PERMAFROST AT NORMAN WELLS, N.W.T.

By

R. A. HEMSTOCK, B.Sc., M.Sc.

February 1949

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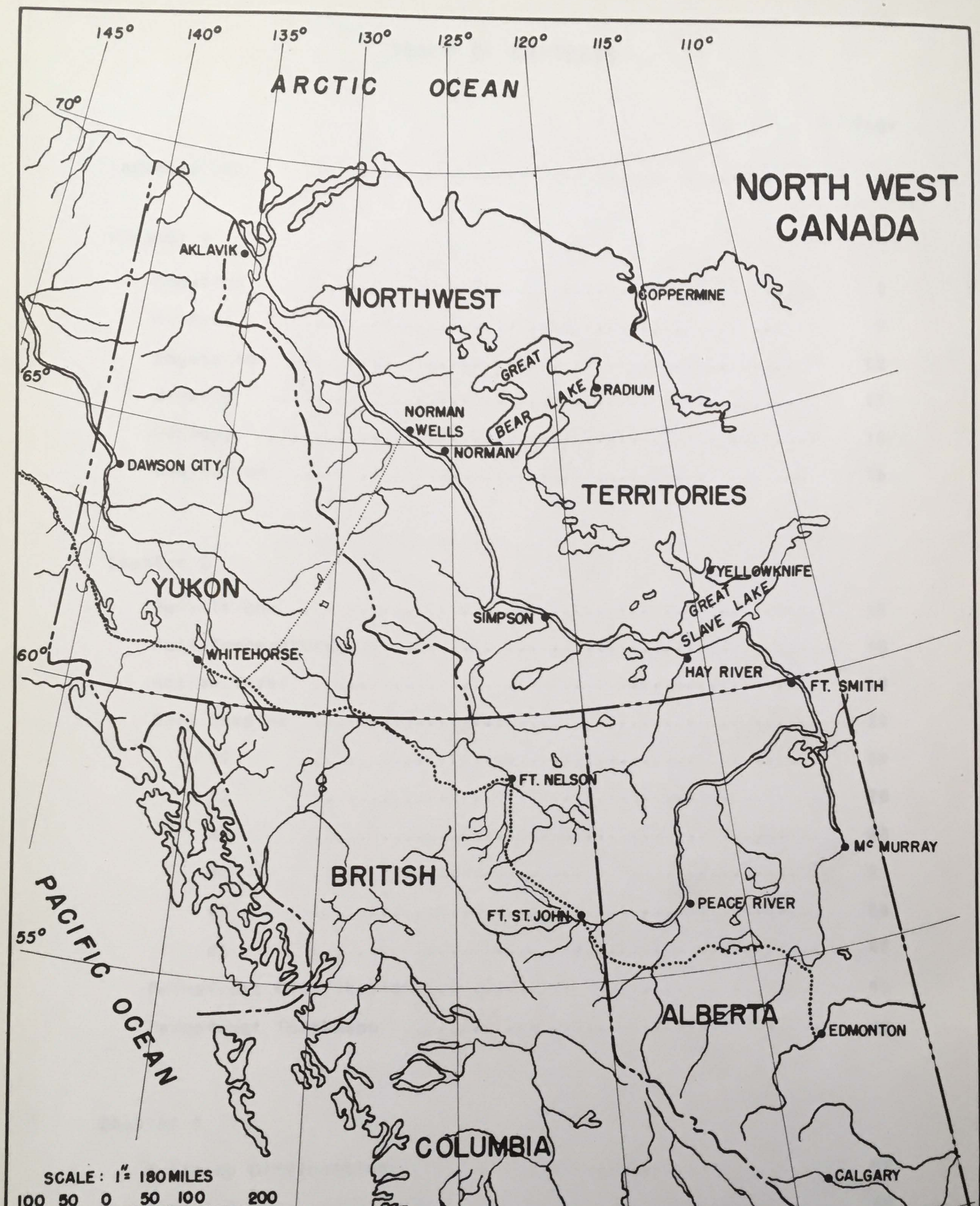
PREFACE

It is with pleasure that I express my thanks to Mr. R. W. MacKinnon, Mr. Angus Sherwood and other members of the Imperial Oil Staff at Norman Wells for their help in obtaining the records in this report.

Dean R. M. Hardy and Mr. S. R. Sinclair of the University of Alberta were also very helpful on some of the technical aspects of the report. Students R. Stollery and G. W. Riddell performed most of the soil tests.

I would also like to express my appreciation to Mr. P. D. Baird and to The Arctic Institute of North America for their assistance, including the supply of reference books which were very useful.

R. A. Hemstock.


NORTH WEST
CANADA
ARCTIC OCEAN
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120°
115°
110°
70°
65°
60°
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50°
AKLAVIK
NORTHWEST
COPPERMINE
GREAT
BEAR LAKE
RADIUM
NORMAN
WELLS
NORMAN
DAWSON CITY
TERRITORIES
YELLOWKNIFE
YUKON
GREAT
SLAVE LAKE
SIMPSON
WHITEHORSE
HAY RIVER
FT. SMITH
FT. NELSON
Mc MURRAY
BRITISH
PEACE RIVER
FT. ST. JOHN
PACIFIC OCEAN
ALBERTA
EDMONTON
COLUMBIA
SCALE: 1" = 180 MILES
100 50 0 50 100 200
CALGARY
VANCOUVER
U. S. A.

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PERMAFROST AT NORMAN WELLS, N.W.T.

INTRODUCTION

A project was undertaken to prepare and furnish a study of all available data on permafrost in the Norman Wells area and on related soil and snow mechanics with a view to improving the present methods of road building, communications and general construction in the Arctic and Subarctic regions.

The work has been carried out in the immediate area of Norman Wells. The main body of the observations have been taken from 1943 to 1948. The work in general is concerned with the industrial developments brought on at this small oil centre by the second Great War. An attempt will be made to describe and evaluate the effects of permafrost in particular and the Subarctic phenomena in general on the various sections of industrial development such as communications, road building, construction in general and on personnel.

The work done during the investigation at Norman Wells, N.W.T. includes a compilation of the maximum and minimum daily temperatures for four years. The general climate is described, precipitation and snowfall records are given. Geology of the region will be dealt with briefly as well as the flora and fauna and other characteristics of the area. Notes have been made on construction methods and details. Road building and communications are discussed. In general an evaluation of the effects of the Subarctic phenomena on all modes of modern civilization in the area is attempted.

CHAPTER I

LOCATION

Norman Wells is a small but strategically important oil centre in the lower Mackenzie Valley. From its oil wells and refinery come the petroleum products to heat, light and power the mining camps, the river transport, and planes of the whole Mackenzie District. The settlement lies in the broad Mackenzie Valley some eighty miles south of the Arctic Circle. (See Frontispiece).

Until the advent of the aeroplane the whole district was considered very remote. The only access to the area was by river boat from Waterways, Alberta in summer, or by the long hard journey overland in winter with dog team. It was almost impossible to contact civilization more than once or twice a year. However, now regular connection with the "outside" world is maintained by a commercial airline. Wireless communication facilities are provided by the Royal Canadian Corps of Signals and link up with commercial telegraphs at Edmonton, Alberta. In summer river boats and barges move freight and supplies from railhead at Waterways, or from the highway terminus at Hay River, N.W.T. on Great Slave Lake. During the war some freighting was done in winter by tractor train, but this practice was discontinued because of high costs involved.

CLIMATE

Figures 1 to 6 show maximum and minimum air temperatures for the years 1943 to 1948 inclusive. A study of these charts shows that the air temperature is subject to rapid and wide variations. The warmest temperature recorded was 96° F on July 18th, 1947. The coldest temperature, -68° F on February 3rd, 1947.

Average yearly temperatures are given below:

Fig. 1	1943	Average Air Temperature	24.0° F
Fig. 2	1944	Average Air Temperature	23.3° F
Fig. 3	1945	Average Air Temperature	21.3° F
Fig. 4	1946	Average Air Temperature	20.7° F
Fig. 5	1947	Average Air Temperature	21.2° F
Fig. 6	1948	Average Air Temperature	20.5° F

From the above we see that the overall average yearly temperature for the past six years is 21.8° F. This is 10.2° below freezing, and according to Sumgin[1] is sufficient to hold and cause aggradation of permafrost.

Records of the Dominion Meteorological Service show averages as follows for snowfall and total precipitation:

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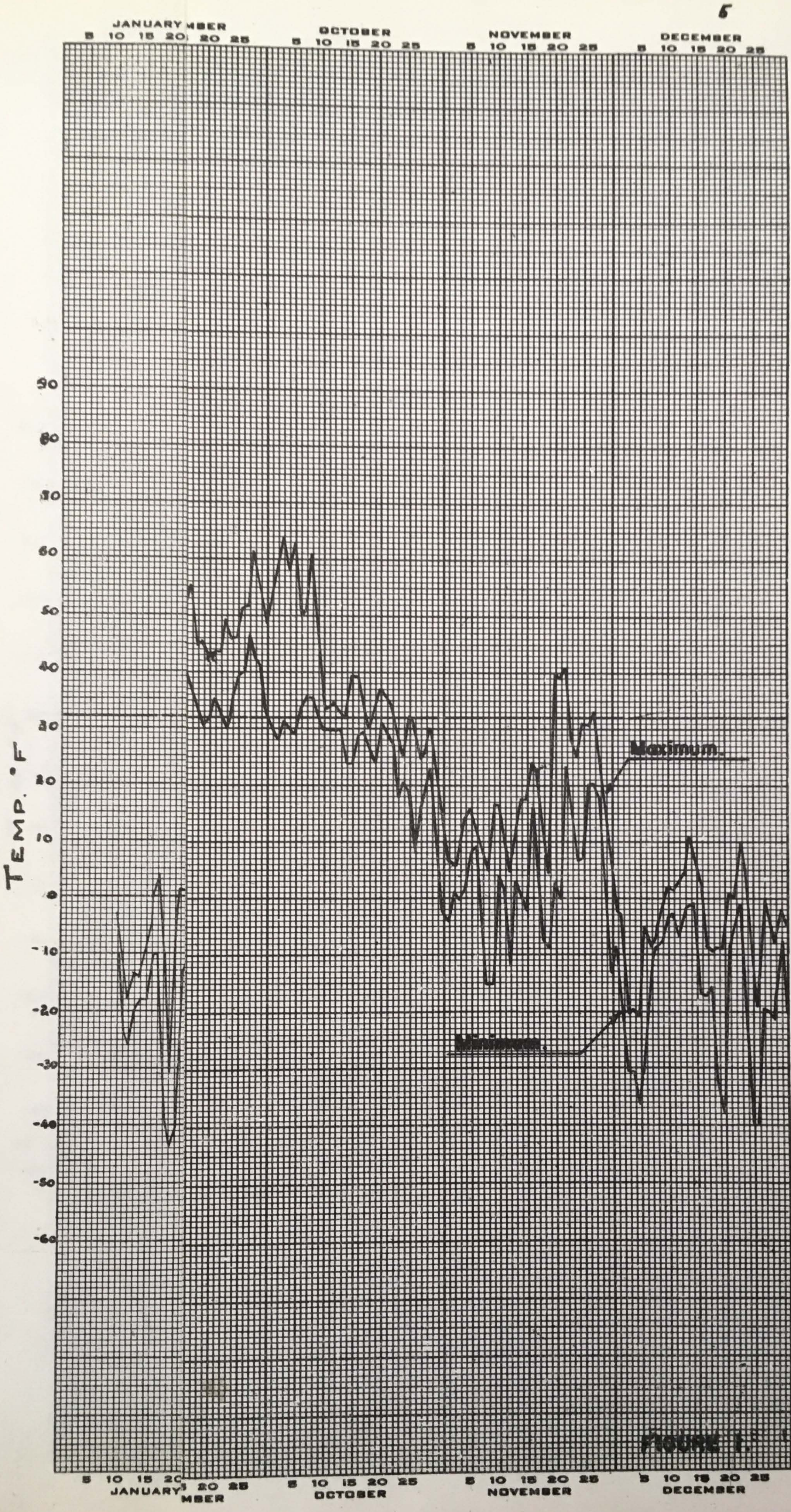
1 - "Permafrost" by S. W. Muller, Page 4

INCHES OF SNOWFALL AND TOTAL PRECIPITATION
AT NORMAN WELLS, N.W.T.

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
1944													
Snowfall	5.3	7.3	7.6	0.9	-	-	-	-	0.3	3.4	6.9	9.2	40.9"
Total Precipitation	0.53	0.73	0.76	0.09	-	-	1.43	2.07	1.97	0.37	0.69	0.92	9.56"
1945													
Snowfall	3.0	4.7	1.6	1.7	-	-	-	-	2.1	T	8.8	7.1	29.0"
Total Precipitation	0.30	0.47	0.16	0.17	0.25	1.13	0.89	4.37	2.05	0.15	0.88	0.71	11.53"
1946													
Snowfall	5.2	4.8	4.7	2.5	0.5	-	-	-	5.2	13.8	6.7	2.8	46.2"
Total Precipitation	0.52	0.48	0.47	0.33	0.90	0.51	1.57	1.68	2.24	1.57	0.67	0.28	11.22"
1947													
Snowfall	6.1	2.5	6.4	3.1	0.7	1.5	-	-	0.2	3.0	7.5	9.2	38.7"
Total Precipitation	0.61	0.25	0.64	0.31	0.24	1.71	0.61	0.90	0.41	0.35	0.75	0.92	7.3"
1948													
Snowfall	8.9	7.4	3.3	14.8	1.6	-	-	T	8.7	19.8	10.1	-	84.6"
Total Precipitation	0.89	0.74	0.33	1.49	1.39	1.56	2.86	3.75	2.42	1.99	1.01	-	18.77"


JANUARY
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5 10 15 20 25
NOVEMBER
5 10 15 20 25
DECEMBER
5 10 15 20 25
TEMP. °F
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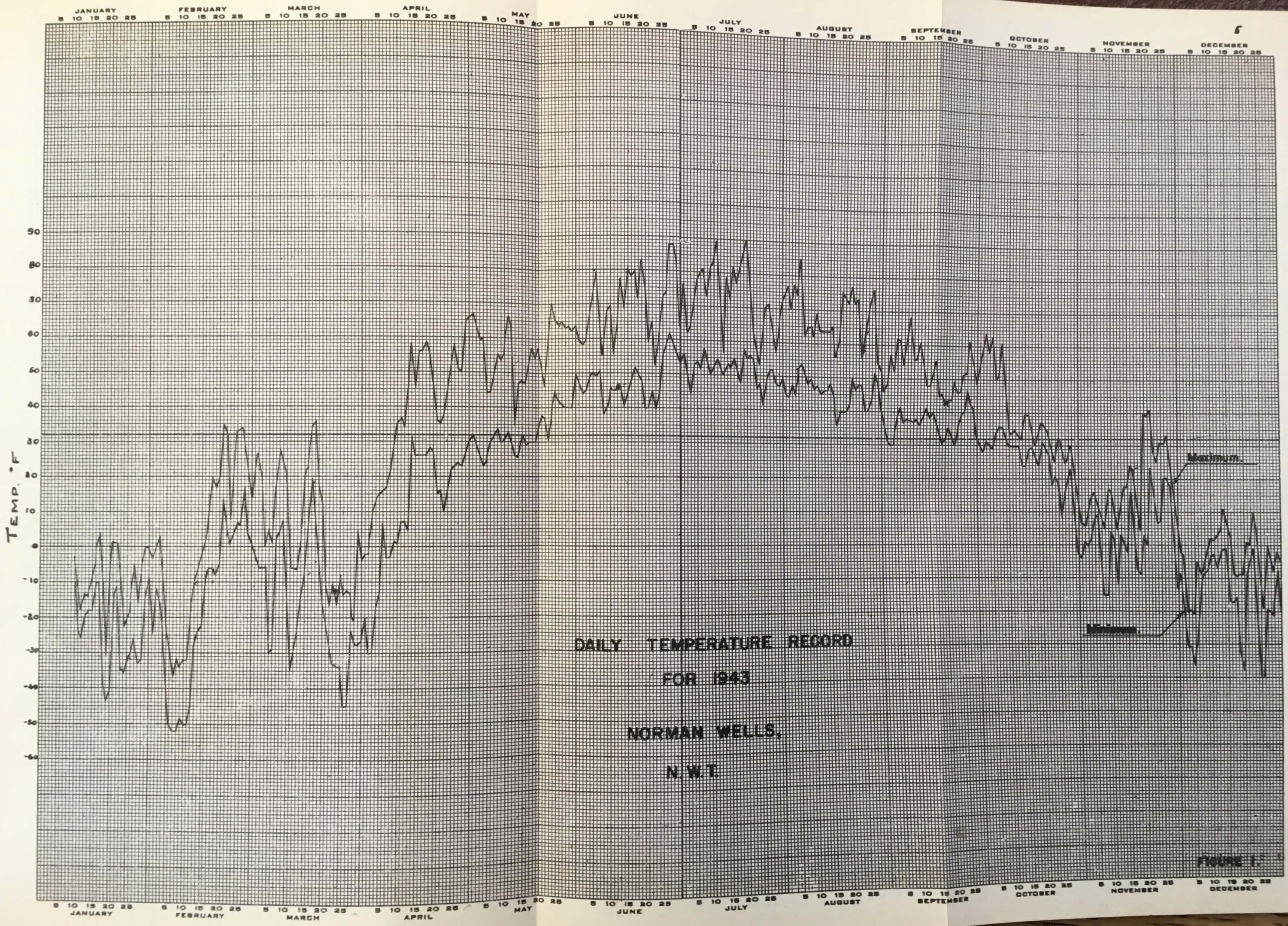
-60
Maximum.
Minimum.

FIGURE 1.


JANUARY
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OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
TEMP. °F
90
80
70
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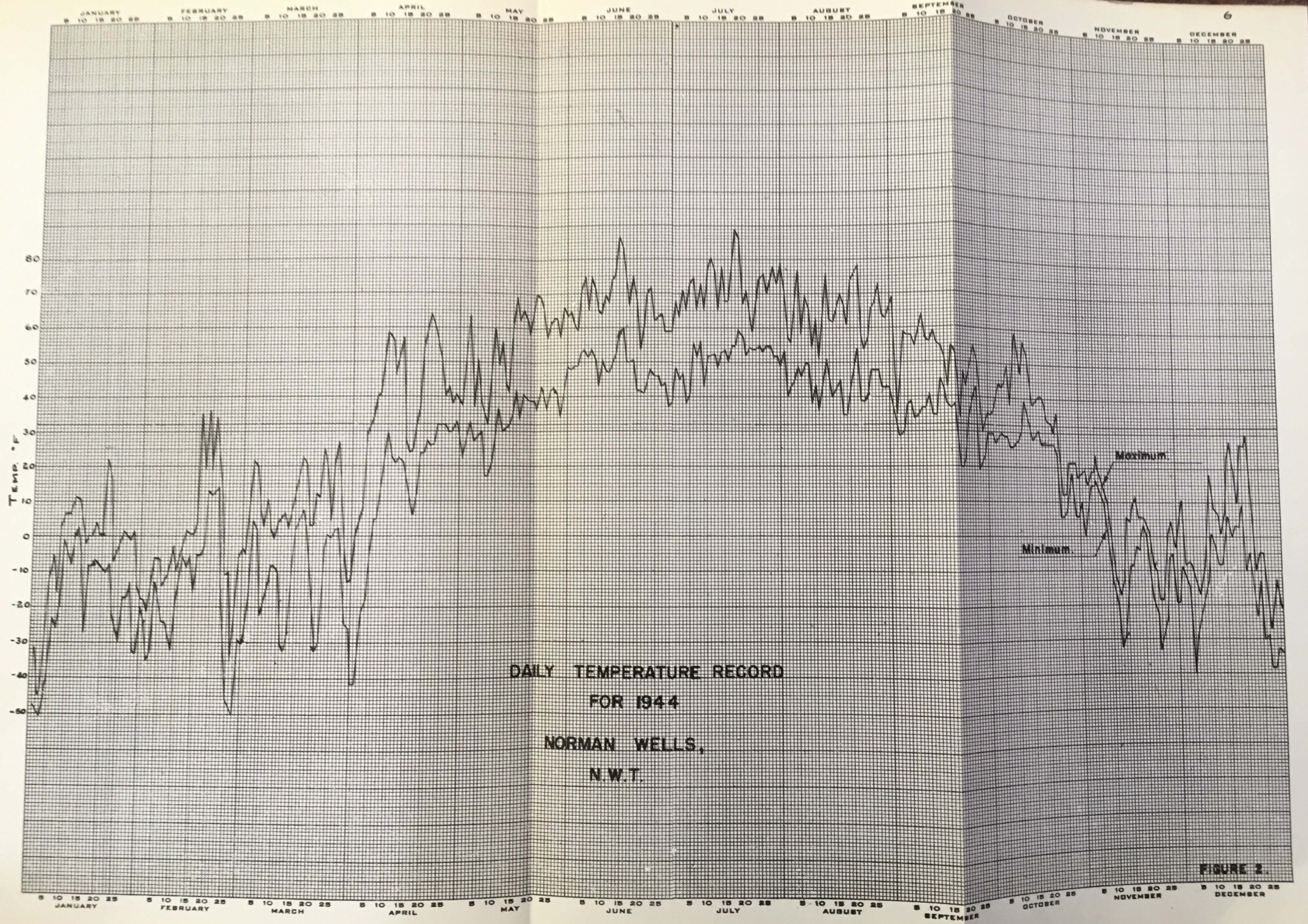
-30
-40
-50
-60
Maximum
Minimum
DAILY TEMPERATURE RECORD
FOR 1943
NORMAN WELLS,
N.W.T.

FIGURE 1.



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OCTOBER
NOVEMBER
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5 10 15 20 25
TEMP. °F
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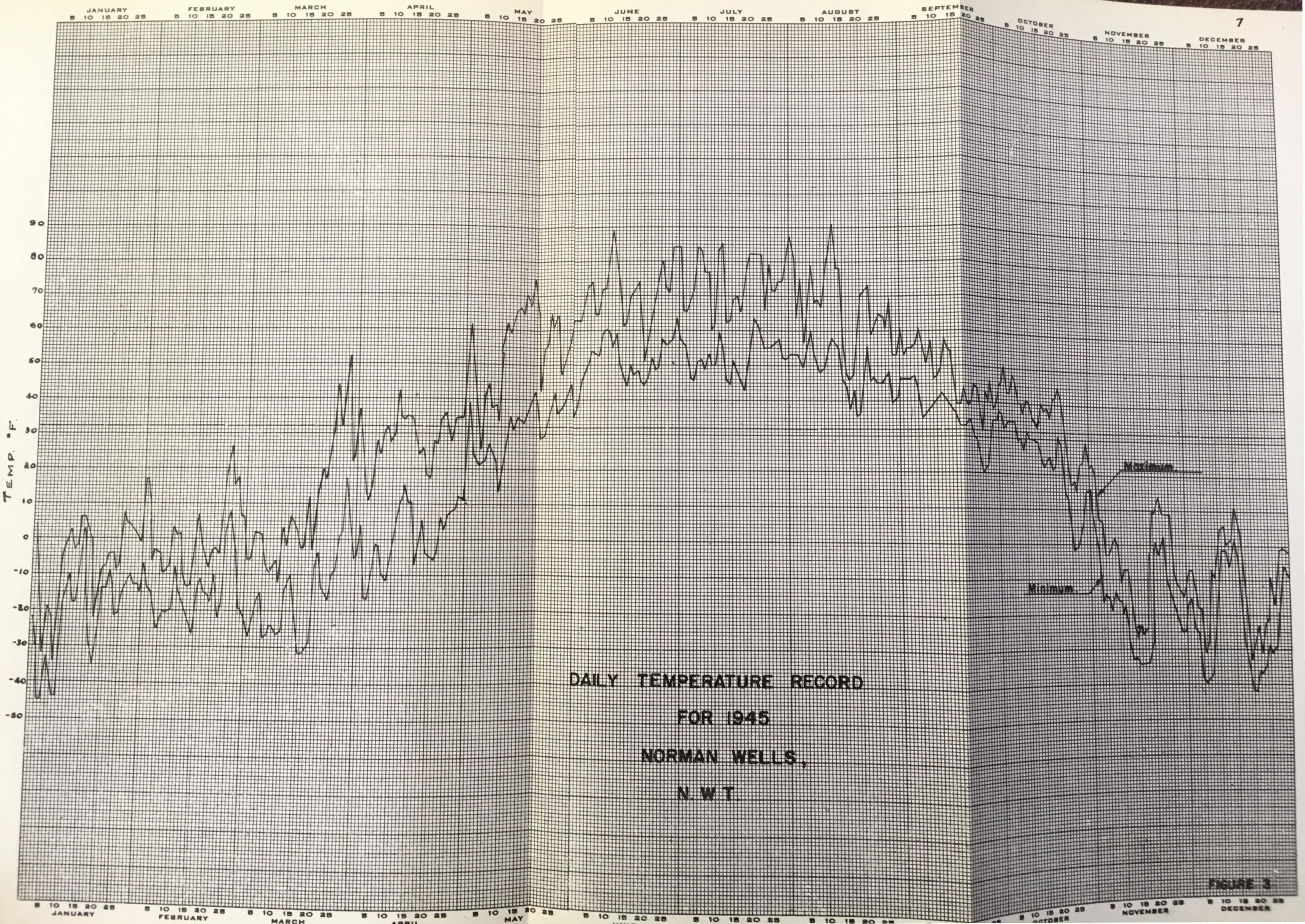
-50
Maximum
Minimum
DAILY TEMPERATURE RECORD
FOR 1944
NORMAN WELLS,
N.W.T.

FIGURE 2.


DAILY TEMPERATURE RECORD
FOR 1945
NORMAN WELLS,
N.W.T.
TEMP. °F
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
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-10
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-30
-40
-50
Maximum
Minimum

FIGURE 3

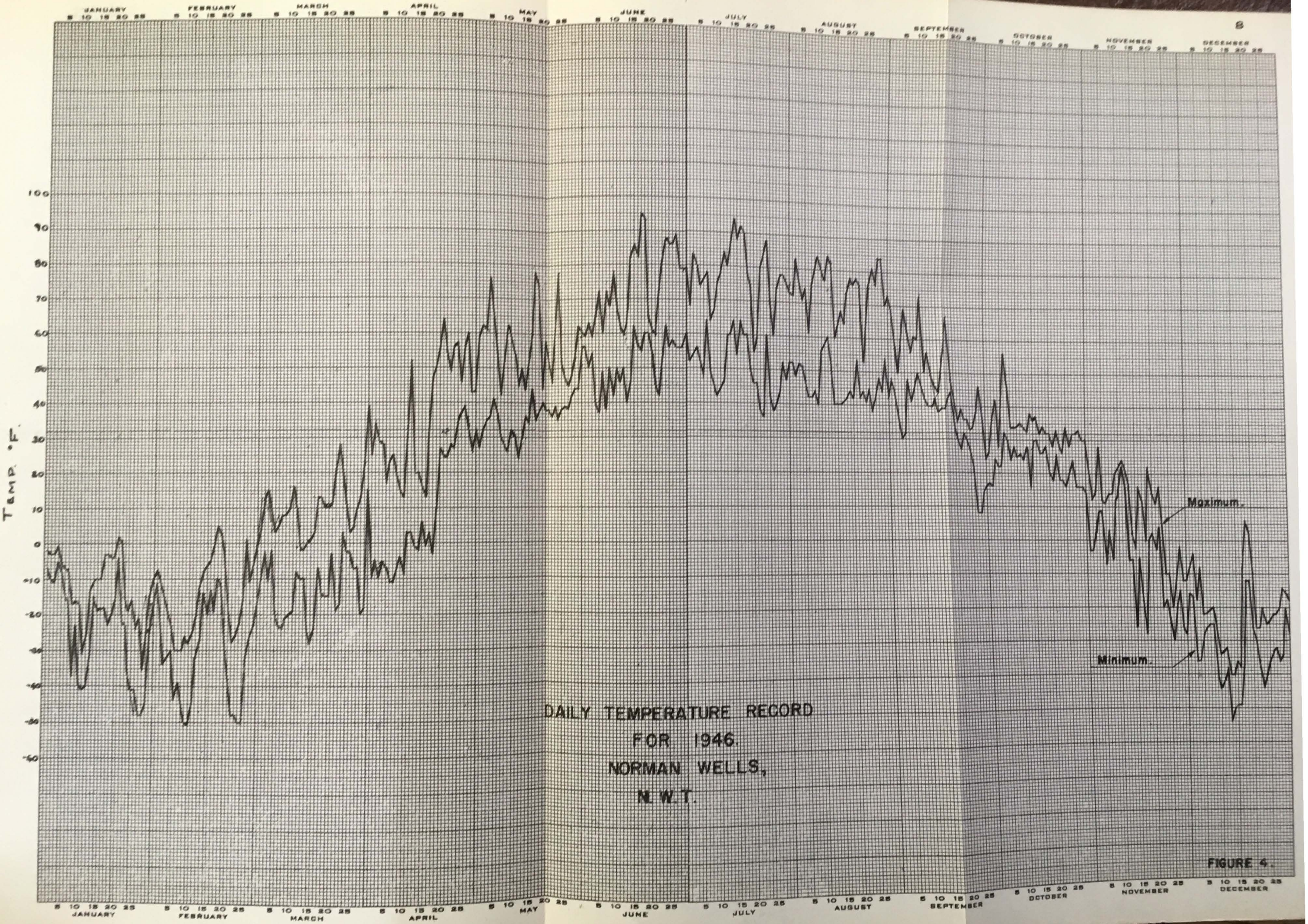
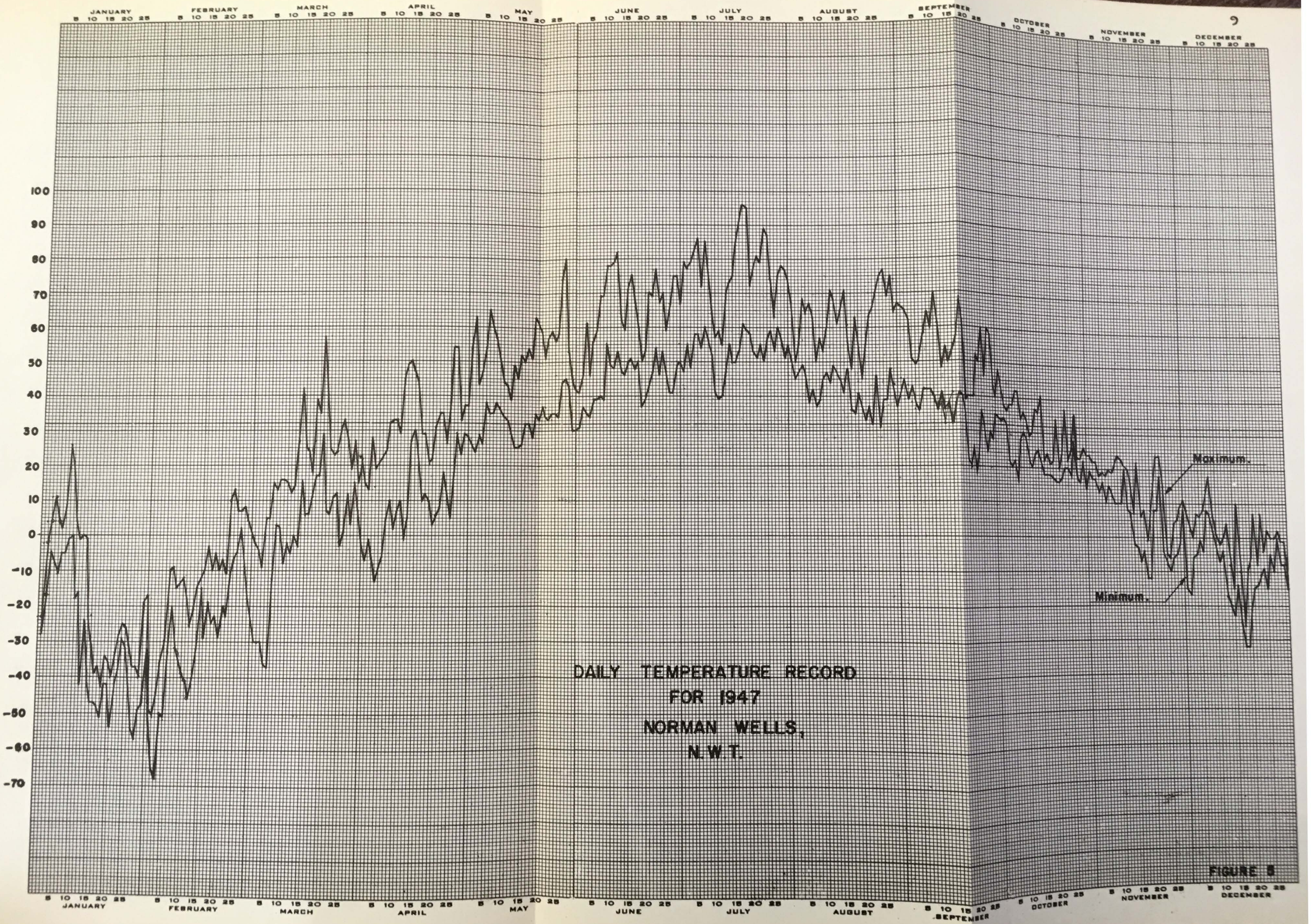

DAILY TEMPERATURE RECORD
FOR 1946.
NORMAN WELLS,
N. W. T.
TEMP. °F.
Maximum.
Minimum.
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE 4.


DAILY TEMPERATURE RECORD
FOR 1947
NORMAN WELLS,
N.W.T.
Maximum.
Minimum.
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
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80
70
60
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30
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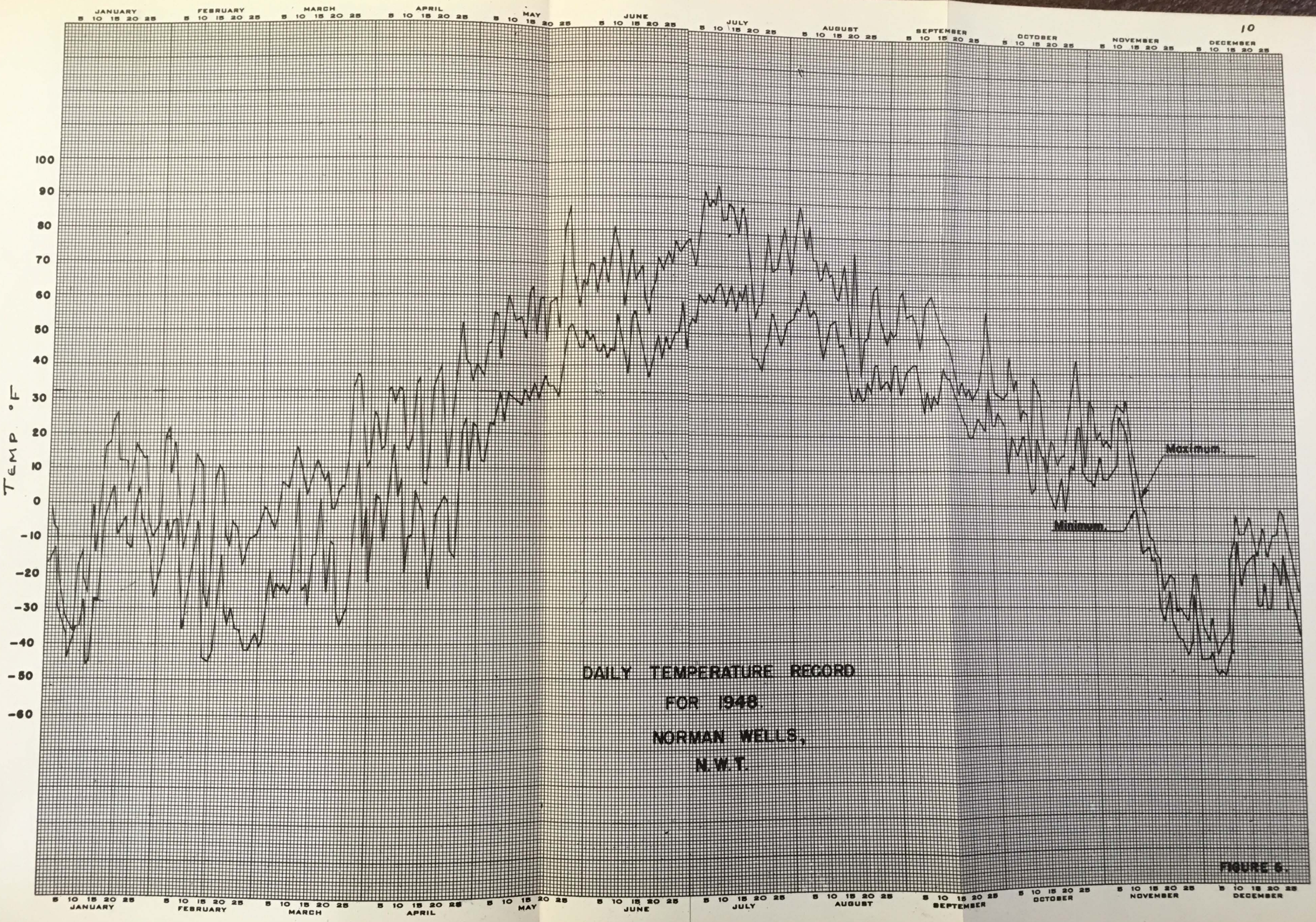
10
0
-10
-20
-30
-40
-50
-60
-70
FIGURE 5



JANUARY
FEBRUARY
MARCH
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JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
TEMP °F
100
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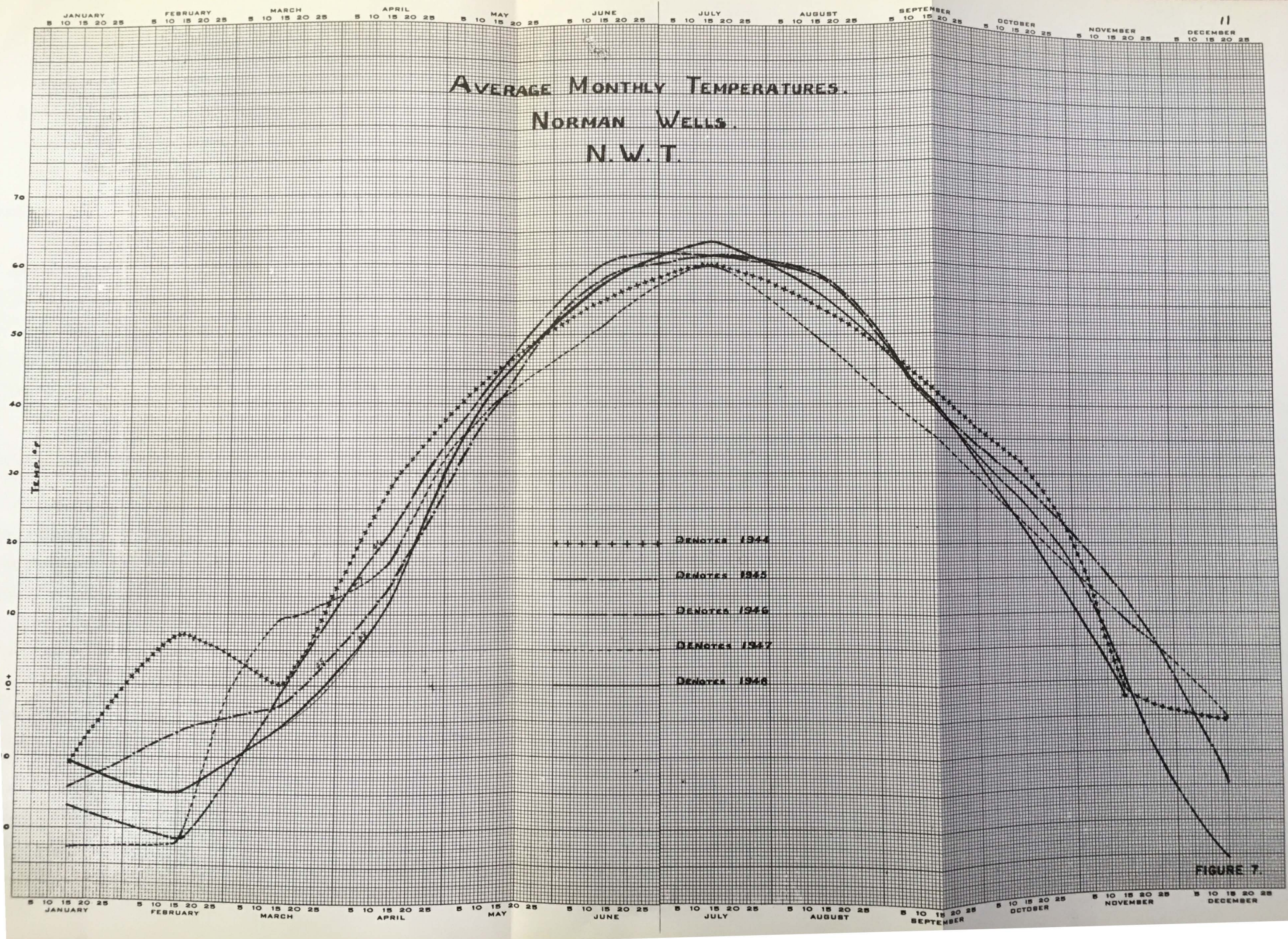
0
-10
-20
-30
-40
-50
-60
Maximum.
Minimum.
DAILY TEMPERATURE RECORD
FOR 1948.
NORMAN WELLS,
N.W.T.

FIGURE 6.


AVERAGE MONTHLY TEMPERATURES.
NORMAN WELLS.
N.W.T.
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
70
60
50
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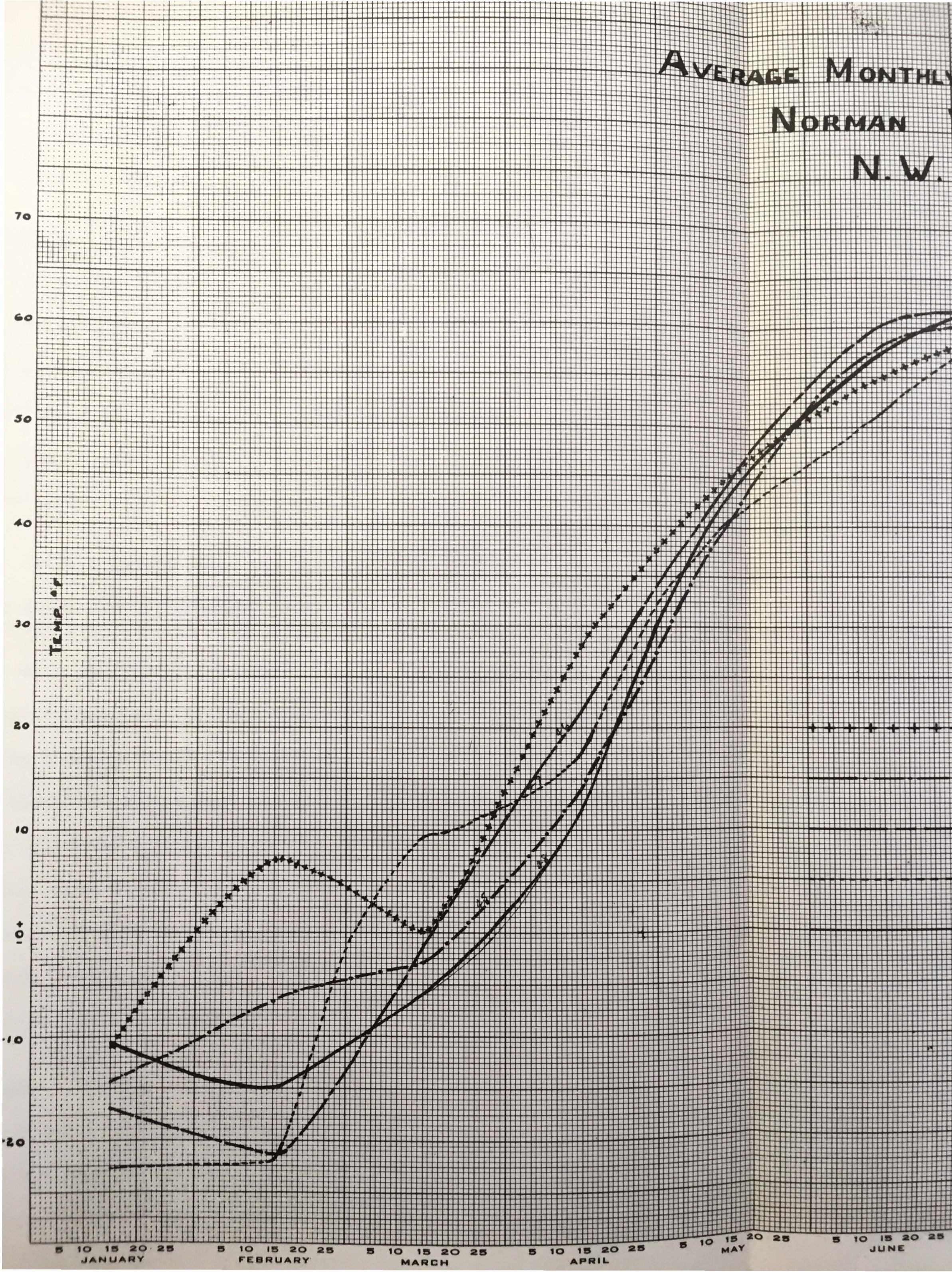
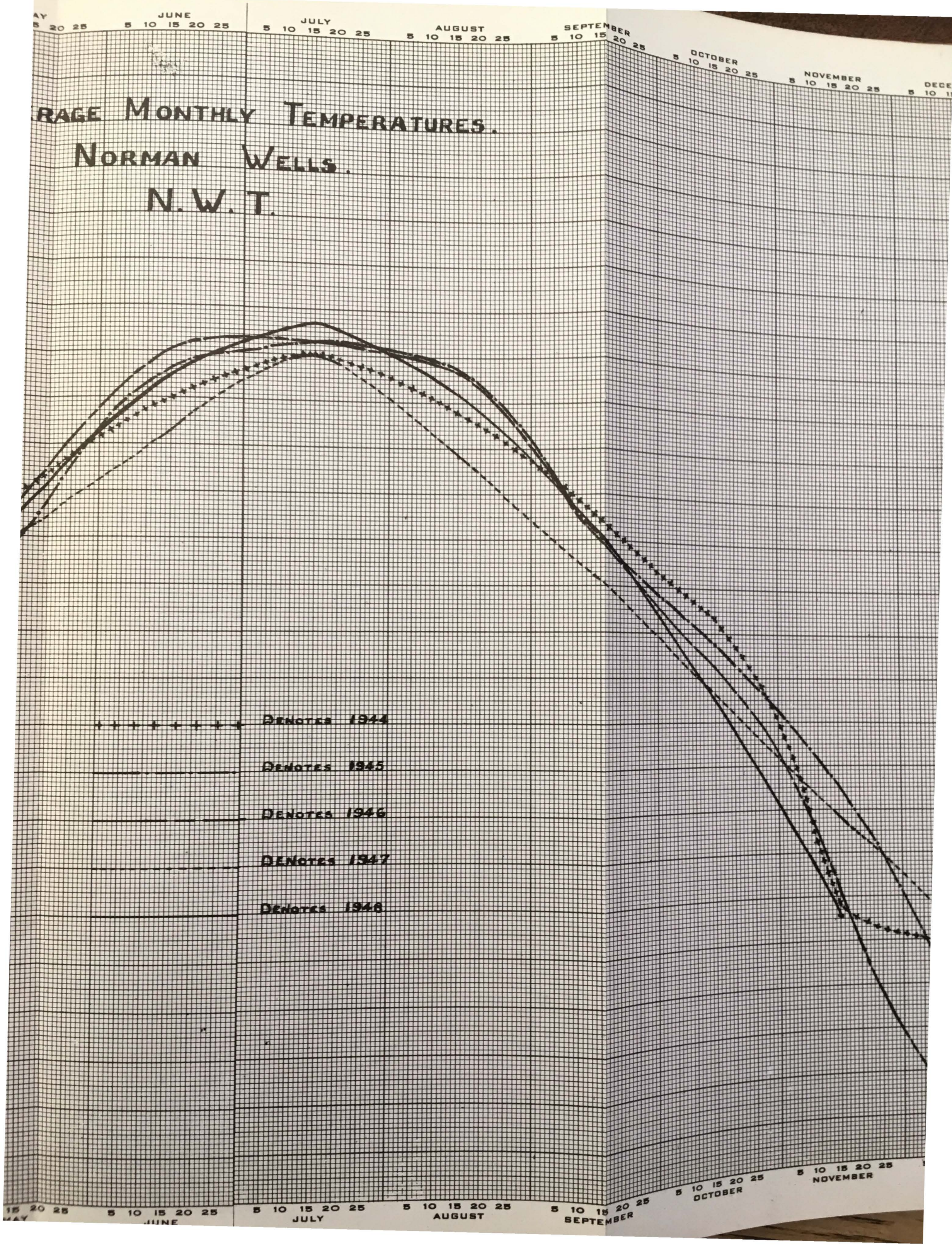
30
20
10
0
TEMP. °F
DENOTES 1944
DENOTES 1945
DENOTES 1946
DENOTES 1947
DENOTES 1948

FIGURE 7.


AVERAGE MONTHLY
NORMAN
N.W.
TEMP. °F
70
60
50
40
30
20
10
0+
-10
-20
5 10 15 20 25
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE


RAGE MONTHLY TEMPERATURES.
NORMAN WELLS.
N.W.T.
DENOTES 1944
DENOTES 1945
DENOTES 1946
DENOTES 1947
DENOTES 1948
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER

TURES.

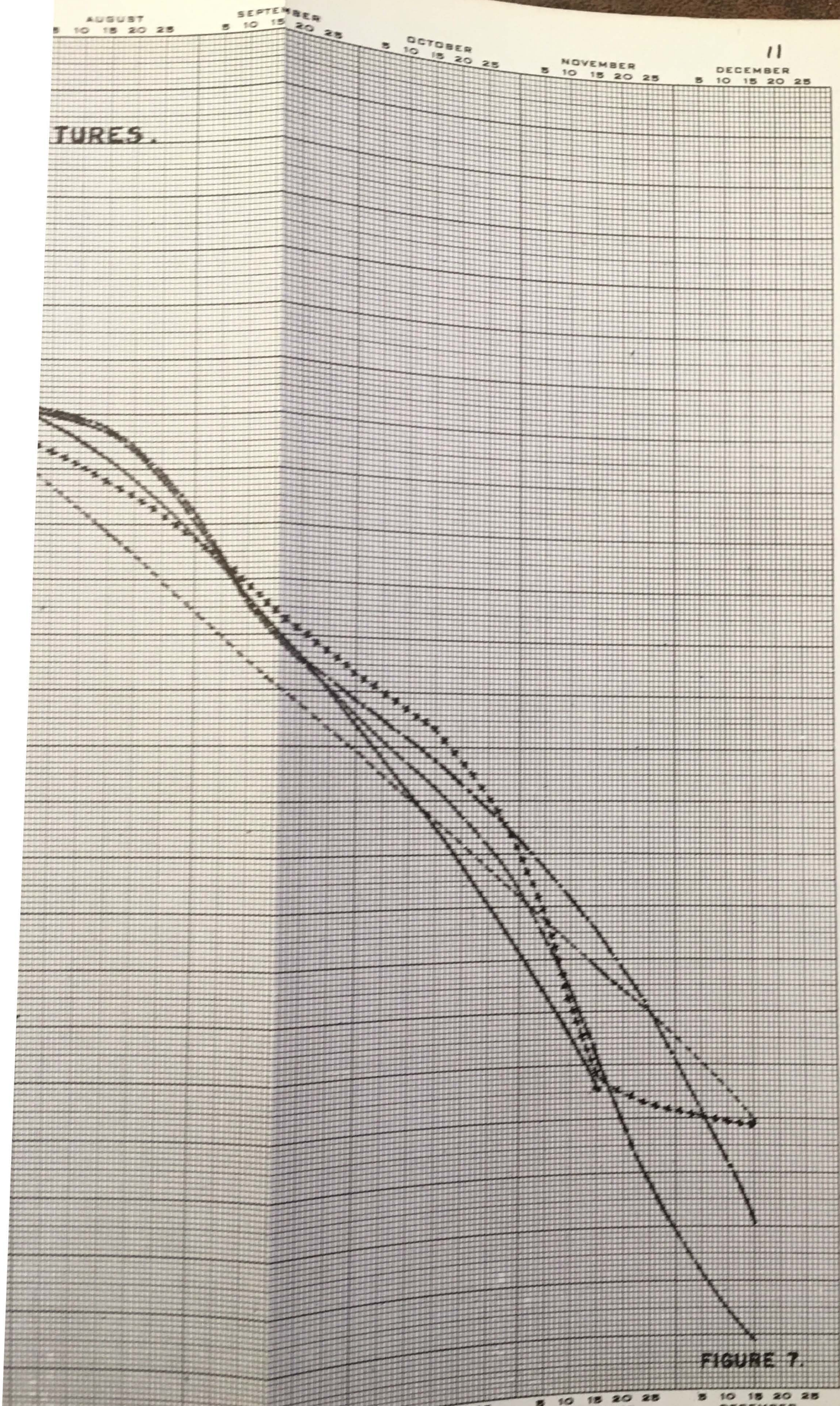
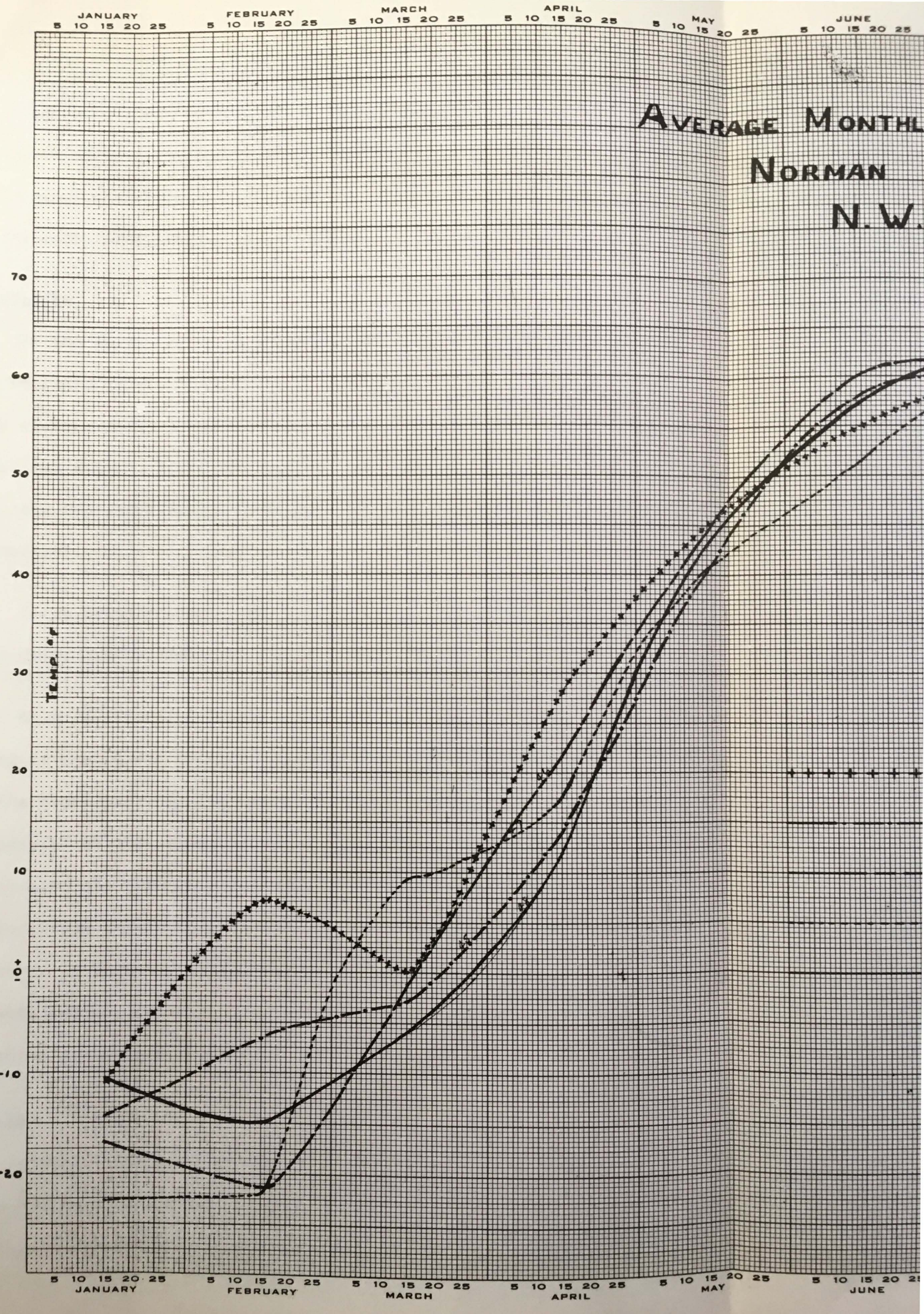


FIGURE 7.


AVERAGE MONTHL
NORMAN
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APRIL
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TEMP °F

The prevailing winds as would be expected, are from the north down the river valley. The presence of mountains on either side of the valley prevent any cross winds. In general the winds are moderate and are fairly continuous in April and May.

VEGETATION

In the valley of the Lower Mackenzie the vegetation is typical of the southern parts of the Subarctic. Of the trees, spruce predominates with stunted white birch, tamarack, aspen and poplar being found in some localized areas. There are no pine trees in the district, apparently the long tap roots of the pine are not adaptable to areas underlain with permafrost.

Large areas of peat bogs are also found, which support growth of only moss, grasses and a very few stunted shrubs.

Wild raspberries, blueberries, currants and strawberries are also found in some areas along the Mackenzie and add greatly to the enjoyment of the countryside during the late summer months. Gardens are quite successful at most points along the valley where the soil has been well cultivated and drained and the permafrost has been forced to five feet or more from the surface. South facing slopes are of course best for gardens. A point of interest here is the comparatively long frost free growing season, see Figs. l - 6, which coupled with the long hours of sunshine gives some remarkable results.

BREAKUP

Snowfall is fairly heavy in the area with average falls running from 2.5 feet to 7.0 feet. Total precipitation is moderate and in an average season amounts to about eleven inches with the greater part fall-

ing in August and September. May, June and July are in general warm and bright, and with the long hours of sunshine and moderate temperatures, they are ideal months for outdoor work. The breakup of the rivers and lakes is generally around the middle of May, with freezeup coming early in November. At both breakup and freezeup there is a period of about six weeks when the normal travel of the North is disrupted. It is during this time that the North is even yet quite isolated. Only land based planes are able to travel and year round airports are widely scattered in the North. Norman Wells has a good airport, built on a glacial esker running parallel to the Mackenzie River. This airport though unsurfaced, is serviceable all year round, except for a few days in the spring.

GEOLOGY

Norman Wells lies in the Mackenzie River Basin on the north-east flank of a syncline approximately twenty miles in width. This syncline is flanked on the north-east by the Discovery (Norman) Range rising to roughly 3000 feet above sea level. Both the Discovery Range and the Carcajou (Mackenzie) Mountains which flank the area to the south-west are formed of Paleozoic rocks.

The syncline is capped unconformably by Cretaceous rocks. Tertiary rocks are also found in some localities. The river course has been controlled in part by the contact of the Mesozoic and Paleozoic rocks. The Cretaceous (Mesozoic) section consists chiefly of shales, interbedded with varying amounts of sandstones with minor bands of ironstone and carbonaceous material. The Paleozoic section consists of interbedded well consolidated sandstones and shales in the uppermost part grading into compact shales, bituminous in the middle portions which at Norman Wells

contains a development of oil bearing reef material. This is underlain by successively older rock series which for the most part are carbonate type rocks such as limestones and dolomite.

The whole valley has been subject to glacial action which has laid an obliterating mantle over much of the area. Only the uppermost peaks and ridges of the more rugged mountain ranges have not been effected. Numerous glacial phenomena such as eskers, moraines, etc., are evident throughout the entire region. Movement of the ice was in general in a north-west--south-east direction. It is generally believed that perma-frost conditions have existed at least since the retreat of this last glacier period.

Poor drainage is typical in the area--numerous lakes and swamps occur throughout the district. Generally these conditions are associ-ated with the flat lying Cretaceous strata lying in the lowermost areas. In the immediate area of Norman Wells particularly, the Mackenzie River has in earlier times formed its natural levees and flood plain type deposits depicted now by the area adjacent to the rising mountain flanks. It is this flood plain material that is so difficult to contend with from an engineering stand point. Under normal conditions of deposition, it would seem impossible that a silt could be deposited with such a high moisture content (200-300%) as we find at Norman Wells. Therefore it must be assumed that ice (water) was introduced as a secondary phase in the forming of this soil. This introduction of moisture can be satis-factorily explained by Taber's hypothesis on the formation of ice lenses in a soil.

HABITATION

A few Indians still live along the Mackenzie River--they are however, rapidly dying out because of the inroads of tuberculosis and other diseases of the white man. Many eke out a meagre existence by trapping during the winter, while some are able to get jobs at the trading posts along the river. Only a handful of whites and halfbreeds are settled along the river to trap. There are of course a few to be found at the widely scattered trading posts along the Mackenzie. Norman Wells has never been a native settlement, and most of the habitants are employees of the various government agencies and of Imperial Oil, and are from other parts of Canada, making their home only temporarily at Norman Wells.

The industry rising from oil at Norman Wells has given somewhat better living conditions here, than are general at other settlements along the Mackenzie. All the living quarters are supplied with gas or oil, many are steam heated and have electricity, sewer and water. A recreation hall and curling rink have been built. Thus, with all the modern conveniences available, and with good recreation facilities, Norman Wells is not what many people would expect of a Subarctic settlement. Certainly with all these advantages the time passes very quickly and pleasantly, and one does not realize he is such a short distance from the Arctic circle.

CHAPTER II

DEFINITIONS

Permafrost has been mentioned so often in this report that perhaps it would be well to define it here, and to describe it as we find it at Norman Wells. Siemon Muller defines permafrost as a thickness of soil or other superficial deposit or even of bedrock at a variable depth beneath the surface of the earth, in which a temperature below freezing has continually existed for a long time.

It might be well to note here the confusion which still exists concerning the various terms connected with permafrost and its study. Siemon Muller suggests the word "permafrost" as an alternative to "permanently frozen soil" or "ever frozen soil" or "permanently frozen ground". The word permafrost seems to have gained wide distribution especially among engineers in the past few years, but its use does have some disadvantages since a verb or verbal noun cannot be made from "permafrost" without confusion. In a very excellent paper, K. Bryan[1] suggests the use of the word "pergelisol" from the Latin per = throughout or continuing + geli = gelare to freeze + sol from solium, the soil or ground. He further suggests various other new terms describing the phenomena connected with "pergelisol". A careful study of new terms now would aid greatly in avoiding confusion between engineers, geologists and other scientists as the study of the Arctic and Subarctic phenomena are continued and more information is gathered.

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1 – American Journal of Science, Vol. 244 – Sept. 1946, K. Bryan, Pages 622-642.

Certainly those terms which are in use today and which have generally been coined rather than derived leave much to be desired. If the terminology is to be improved however, then it should be done before the terms now in use become too firmly rooted in the literature on the North.

Muller's definition of permafrost defines entirely on the basis of temperature, and does not indicate texture or character of the frozen material. It would seem however, that the soil so widespread in Northern Canada and Alaska--that is a fine silty frozen soil with high percentages of segregated ice, the soil with which any kind of engineering is difficult and which has characteristics all its own, should be given a distinguishing name. It is much like frozen muskeg--waterlogged, spongy, and almost bottomless when thawed, with no shear strength whatever. The author would therefore propose a word to name this soil--a combination of permafrost and muskeg--permakeg. Here again the "coining" of a word may be objectionable from the scientific standpoint, and in a review of the terminology it might be found that the usage here could better be described by some other word. The author does wish to emphasize however the importance of noting the special characteristics of that soil in the North which contains large quantities of segregated ice, and which cannot be adequately described by the word permafrost.

The "permakeg" at Norman Wells has a base of fine silt, see Fig. 21. The surface material (1" - 12") has a very high content of partially rotten vegetable material which is easily broken and has a spongy feeling. Ice occurs throughout the depth of the soil in lenses of clear ice and in vugs or cleavage planes as crystals. The crystals vary from 1/16" to 1/8" cubes and have the appearance of compressed snow. They resemble

closely the firn[1] ice described by Muller. The soil may be bored with the ordinary corkscrew coal augur, or with a steam jet. Once the surface of vegetation and humus is removed the frozen soil is firm and has all the strength of bedrock as long as it remains in the frozen state.

No reliable proof of taliks (unfrozen layers) (tabelisol-Bryan) have been found during the work at Norman Wells. Reports have indicated a thawed layer at a depth of sixteen feet on one of the permanently frozen islands in the river, and it has been stated that there are several thawed water bearing layers across the river from Norman Wells. None of these statements have been verified however.

SOIL TEMPERATURES

Temperature readings have been taken at many locations in permafrost and under many conditions. They will be considered later under pile reports, but in general indicate a minimum temperature of about 26° F at forty feet and about 28° F at a depth of ten to twenty feet--the depth normally involved in light foundations.

As is general in the Subarctic areas, permafrost is very important from an engineering standpoint at Norman Wells. Its depth from the surface varies greatly with the vegetation, the general lay of the land, and with local conditions, such as rivers, lakes, springs and so on. Observations at Norman Wells taken during the period 1943-1948 give the averages for air temperatures over the year. The yearly average for this

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1 - "Permafrost" by S. W. Muller, Page 32.

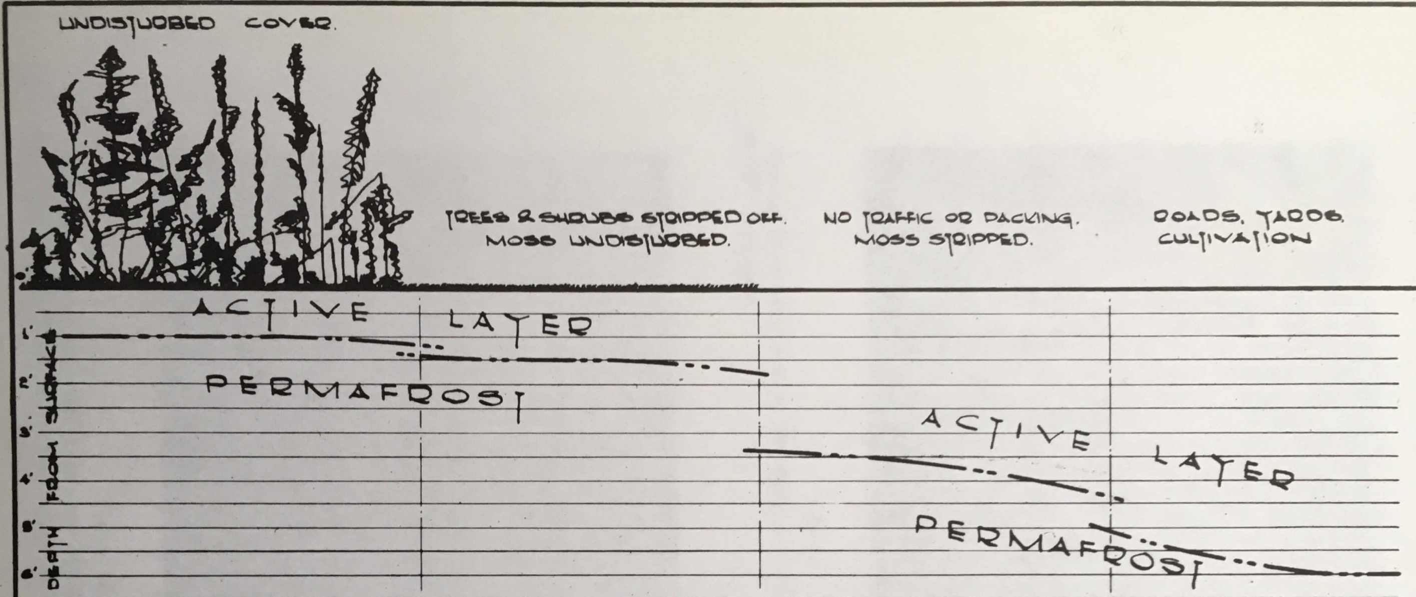
period has been shown to be 21.8° F. Fig. 7 also shows the monthly average over the year. The twenty year average for Fort Norman some forty miles upstream is given by the Dominion Meteorological Service as about 21° F.

ACTIVE LAYER (MOLLISOL)

Depth of permafrost from the surface is indicated by Fig. 8. Here we see the effect of surface cover. Frost recedes in summer to four feet six inches or five feet in sunny areas where most of the vegetation has been removed. On the other hand, the marked effect of vegetation or cover is shown where frost only recedes about a foot below the surface even in midsummer. This diagram has been compiled from several readings of frost depth taken during July and August in various locations around Norman Wells. It is intended to indicate in a general manner the maximum amount of thaw one should expect under the various cover conditions shown. Typical cover is illustrated in Fig. 9. This is the scrub spruce with alder underbrush and heavy mossy, peat surface that is found so commonly up and down the lower Mackenzie River Valley. Fig. 10 shows a typical area stripped of trees and brush but with moss still relatively undisturbed.

The layer of surface soil which is subject to seasonal freeze and thaw is termed the active layer by Muller - (Mollisol - Bryan). It is in this layer of soil that frost heaving occurs so commonly at Norman Wells.

As would be expected, the moisture contents of soil are very high close to the permafrost surface (136-300%). Only in well drained soil



THICKNESS OF ACTIVE LAYER

SUMMARY OF TESTS SHOWING THICKNESS OF ACTIVE LAYER. i.e. DEPTH OF MAXIMUM THAW FOR VARIOUS CONDITIONS OF THE SURFACE AT NORMAN WELLS. TESTS TAKEN DURING AUGUST 1948

FIG. 8.

Figure 9
Typical brush and cover in the Mackenzie Valley. Frost here is out about 15" to 18" in August.

Figure 10
The area here to the side of the road has been stripped of brush but moss has been left intact. Frost is out here about 20" in August.

where frost recedes at least four feet do we find the surface drying enough to be stable. The high moisture content unless allowed for, greatly effects any structure or loading of the surface. Shearing resistance of the wet silt above permafrost is practically nil.

Water freezing above the permafrost, i.e. in the active layer, is the cause of frost heaving, frost mounds and of icings. A careful study of the regime of this water should be made before any construction is attempted which might be effected by this layer. This water is of little use as a water supply because it is seasonal and may very often become polluted.

SOIL SAMPLES

In order to determine the physical characteristics from the point of view of soil mechanics of the soil at Norman Wells, several samples were taken from various locations in the vicinity. Each sample was taken as a representative of some one soil type or to illustrate some one condition existant there. Those samples which were frozen were kept in that state by refrigeration until they were tested at a soils laboratory. All samples were taken in metal containers carefully sealed and labelled.

SAMPLE NO. 1

This was a sample of frozen soil, undisturbed taken from a depth of fifteen inches to a depth of twenty-five inches below the surface of the ground. The location was one of the typical low, poorly drained areas of the region. Trees and brush had been stripped off but the moss had been left intact. Frost was encountered fifteen inches from the surface.

The following is a brief summary of the data obtained from this sample:

Sample taken	- July 28th, 1948.
State	- Frozen, undisturbed
Specific Gravity	- 2.01
Specific Gravity of Screened Material (#40 Mesh)	- 1.91
Moisture Content	- Average of 6 tests 252.0%
Pressure Void Ratio Curve	- See Fig. 11
Grain Size	- Similar to that shown in Fig. 21

The main points of interest here are the very low specific gravity and the high moisture content. The dry soil in the laboratory seemed very fine and light with little body. A specific gravity as low as 1.91 would indicate immediately that the soil was peculiar and when coupled with high moisture content it becomes obvious that the soil would be very difficult to handle from an engineering standpoint. Individual moisture contents ran to 322.% by weight.

(Sample No. 1 - cont'd)

The pressure void ratio curve is plotted from results of a consolidation test run at an average of about 22° F. It is interesting to note the sharply defined break and typical shape of the curve which has been obtained in the test of this frozen sample. This is a typical permakeg soil and is the soil on which the majority of Norman Wells construction is founded.

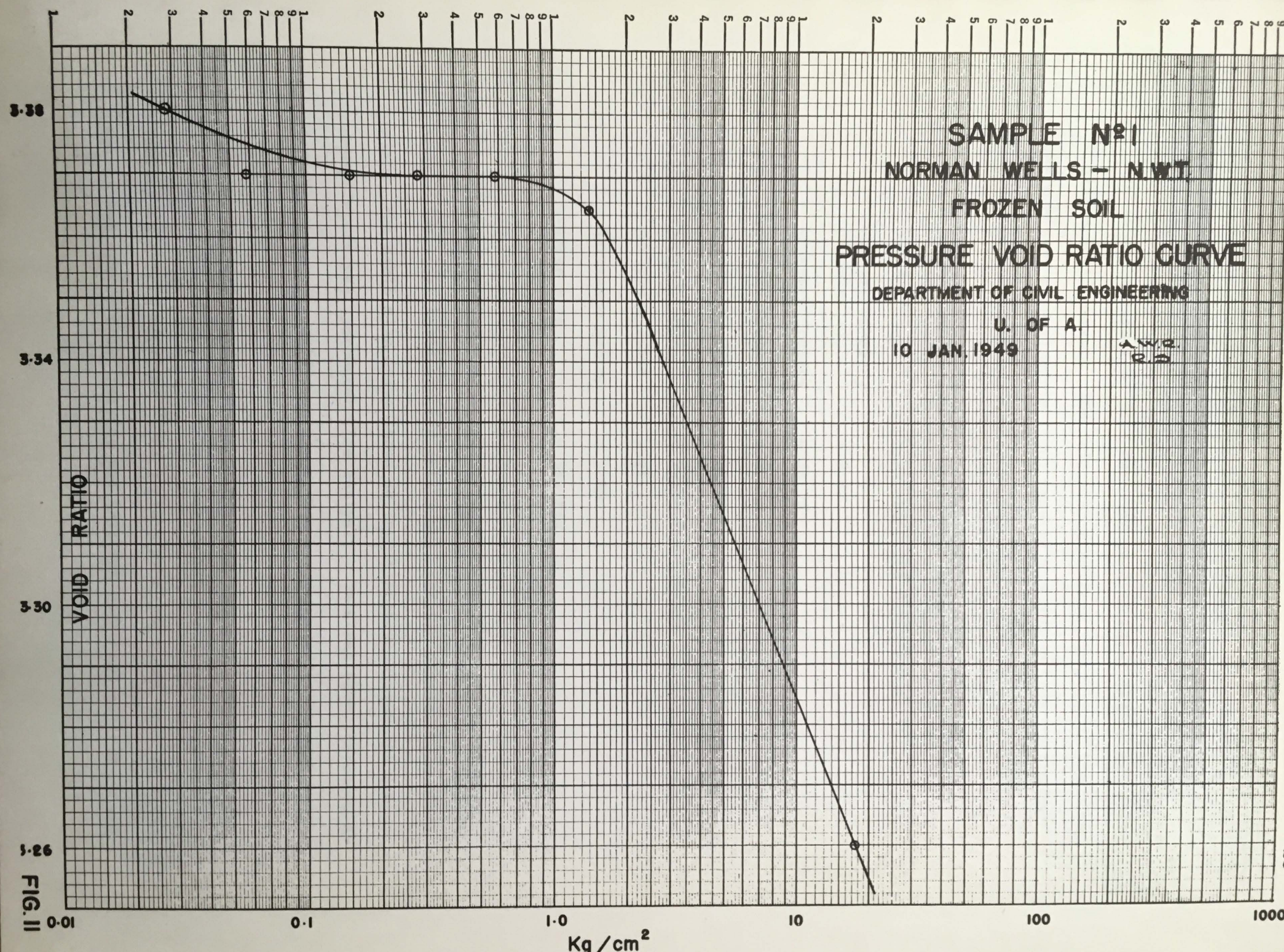

SAMPLE Nº I
NORMAN WELLS — N.W.T.
FROZEN SOIL
PRESSURE VOID RATIO CURVE
DEPARTMENT OF CIVIL ENGINEERING
U. OF A.
10 JAN. 1949
VOID RATIO
3·38
3·34
3·30
3·26
0·01
0·1
1·0
10
100
1000
Kg / cm²

FIG. II

SAMPLE NO. 2

This was a sample of fill material used to cover swampy wet soil to give a working area. The fill was taken from the bank of the Mackenzie River, no noticeable frost heaving occurred in this particular soil at this location.

Sample taken	- July 29th, 1948
State	- Unfrozen and disturbed.
Specific Gravity of Material	- 2.67
Moisture Content	- 25.3%
Plastic Limit	- 25.4%
Plasticity Index	- 10.6%
Liquid Limit	- 36.2% see Fig. 12
Shrinkage Limit	- 21.7
Shrinkage Ratio	- 1.65
Grain Size	- See Fig. 13

The results here show a normal specific gravity and moisture content. The limit tests too indicate a soil not too difficult to deal with. The grain size curve shows an inconsistency between the sieve analysis and the hydrometer size analysis. This has been indicated by a dotted line and could possibly be due to flocculation in the hydrometer sample.

This soil was obtained from a borrow pit and seemed very satisfactory as a fill material. The grain size curve shows that it should not be subject to frost heaving and this was borne out well in actual

(Sample No. 2 - cont'd)

practice. The grain size analysis becomes very important in the North in helping the engineer determine the soils which will give the least trouble due to frost action.

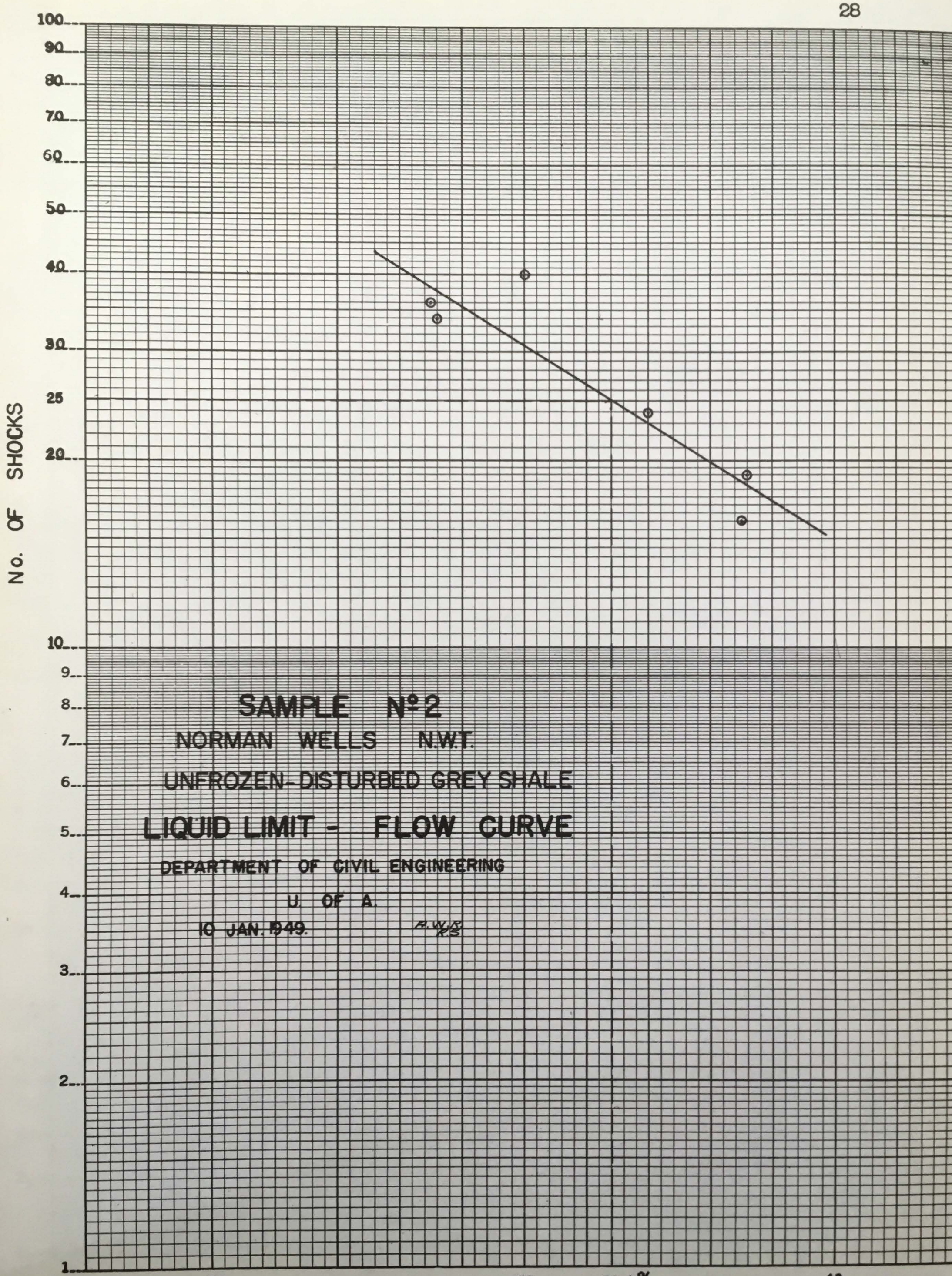

100
90
80
70
60
50
40
30
25
20
10
9
8
7
6
5
4
3
2
1
No. OF SHOCKS
30
35
36.4 %
40
MOISTURE CONTENT
SAMPLE Nº 2
NORMAN WELLS N.W.T.
UNFROZEN-DISTURBED GREY SHALE
LIQUID LIMIT - FLOW CURVE
DEPARTMENT OF CIVIL ENGINEERING
U OF A
10 JAN. 1949.

FIG. 12

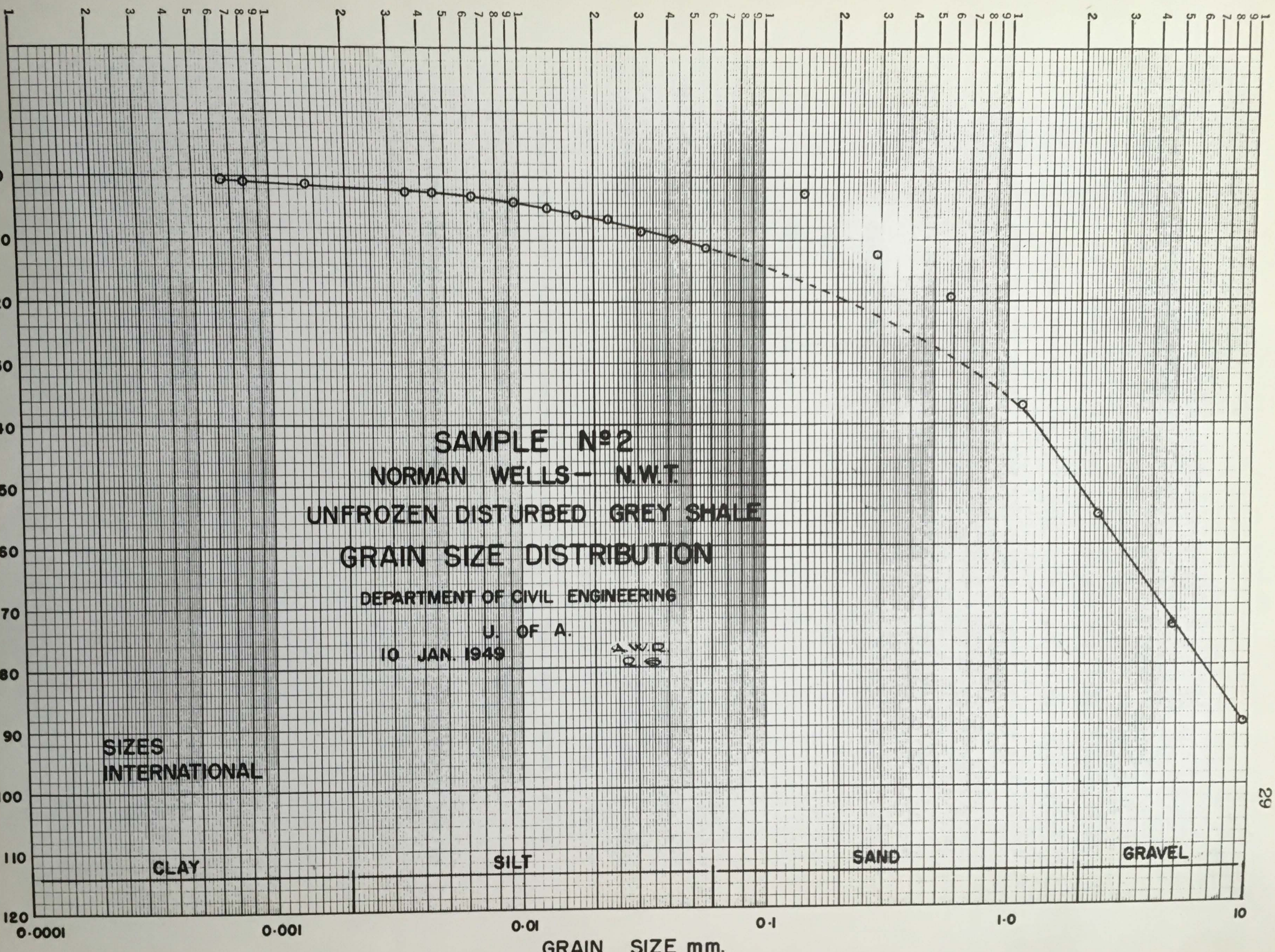

SAMPLE Nº 2
NORMAN WELLS — N.W.T.
UNFROZEN DISTURBED GREY SHALE
GRAIN SIZE DISTRIBUTION
DEPARTMENT OF CIVIL ENGINEERING
U. OF A.
10 JAN. 1949
A.W.R.
% FINER THAN
GRAIN SIZE mm.
SIZES
INTERNATIONAL
CLAY
SILT
SAND
GRAVEL
0.0001
0.001
0.01
0.1
1.0
10
0
10
20
30
40
50
60
70
80
90
100
110
120

FIG. 13

SAMPLE NO. 3

This was a sample of unfrozen soil undisturbed, taken from a depth of six to sixteen inches. The soil was a dirty gravel material which had been used as fill material and had caused a good deal of trouble because of excessive frost heaving. It lay over permakeg and had a fairly high moisture content which increased with depth.

Sample Taken	- July 29th, 1948
State	- Unfrozen, undisturbed.
Specific Gravity	- 2.26
Moisture Content	- 100.9%

High moisture content from segregated ice due to frost heaving is demonstrated in this specimen. The specific gravity is abnormally low but is not as low as that found in some other soils in the area. It would however indicate something unusual in the soil and emphasize the necessity of taking extra precaution with it in any construction.

No results could be obtained from the consolidation test run on the sample.

SAMPLE NO. 4

This was a sample obtained from a road ditch on ground with a little better than average drainage. The area had been stripped of all vegetation and moss and frost has receded to about five feet from the surface. Therefore all segregated ice had melted and the sample assumed the properties of a wet sandy clay.

Sample Taken	- July 31st, 1948.
State	- Unfrozen, undisturbed.
Specific Gravity of Material	- 2.76
Moisture Content	- 17.5%
Plastic Limit	- 21.7%
Plasticity Index	- 2.0%
Liquid Limit	- 23.7% - see Flow Curve Fig. 14
Shrinkage Limit	- 17.3
Grain Size	- See Fig. 15

The specific gravity and moisture content of this sample are normal. The grain size curve indicates that the soil would be subject to frost heaving and this was found to be true in practice. This type material is of glacial origin and is fairly abundant near Norman Wells. As a building site it is very much better than the permakeg type of material as indicated in Sample No. 1 but it is subject to frost action and is therefore not too satisfactory as a fill material or for roads or airports.

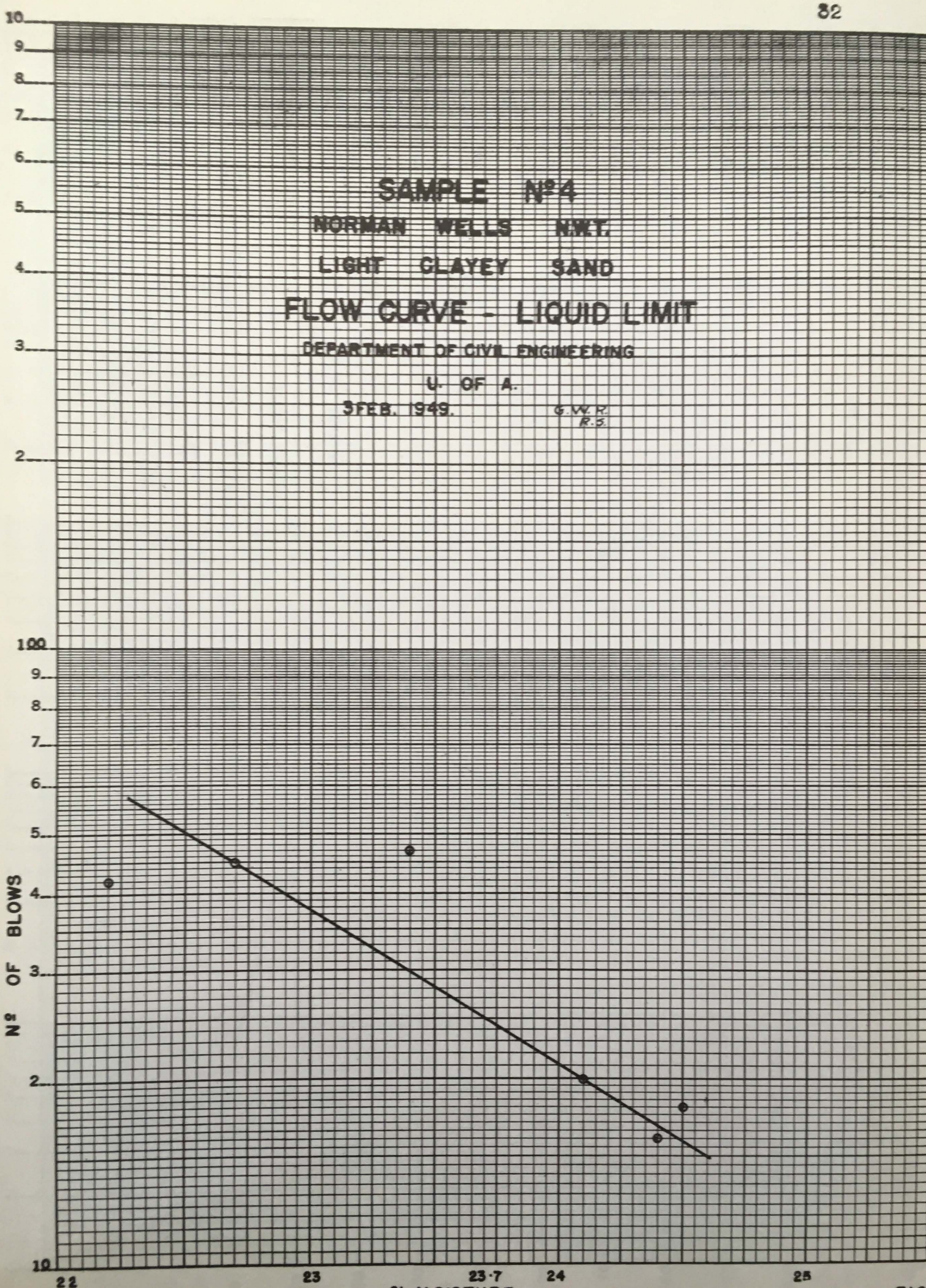

SAMPLE Nº4
NORMAN WELLS N.W.T.
LIGHT CLAYEY SAND
FLOW CURVE - LIQUID LIMIT
DEPARTMENT OF CIVIL ENGINEERING
U. OF A.
3 FEB. 1949.
G.W.R.
R.S.
Nº OF BLOWS
10
9
8
7
6
5
4
3
2
100
% MOISTURE
22
23
23·7
24
25

FIG. 14

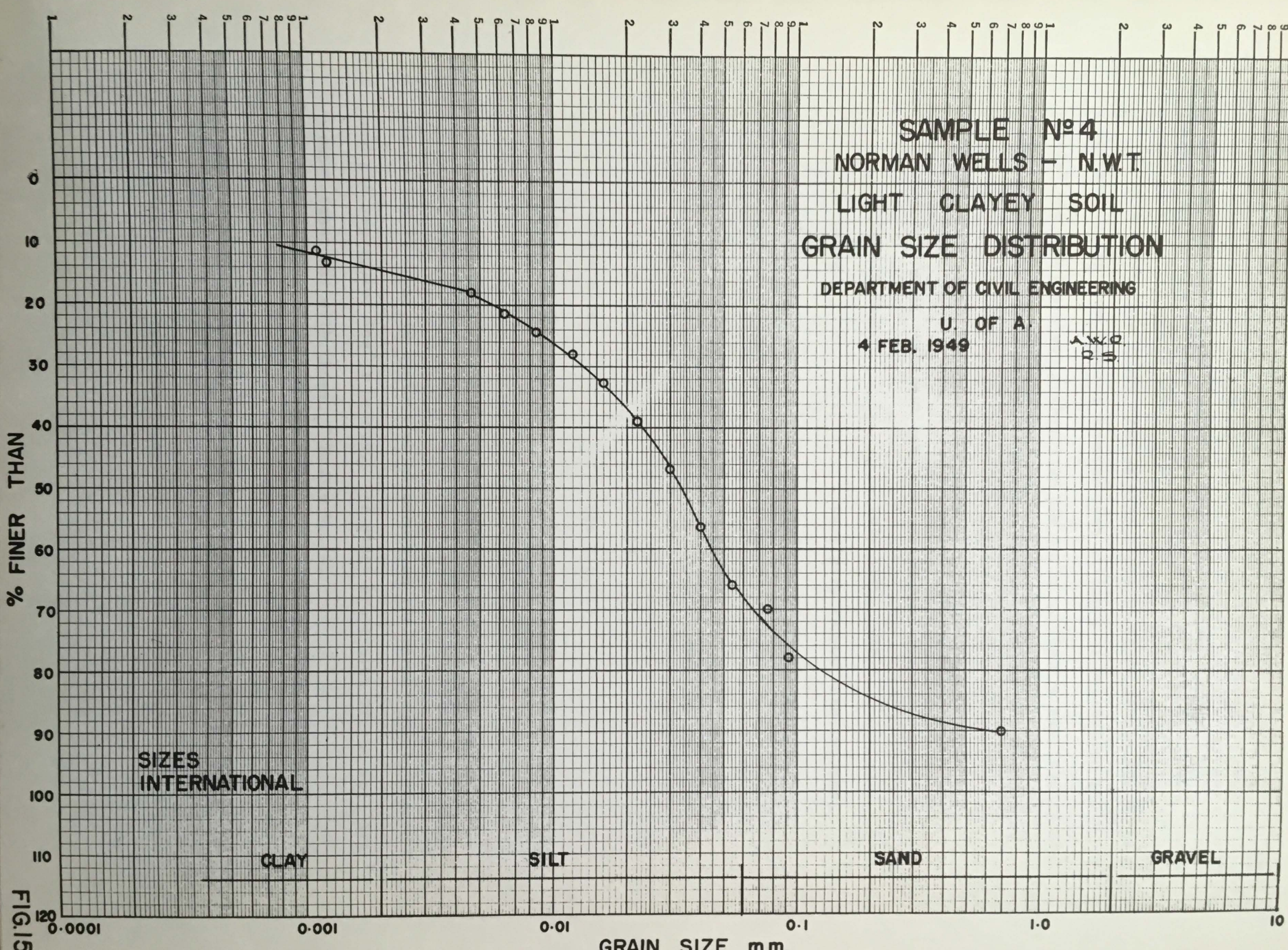

SAMPLE Nº 4
NORMAN WELLS - N.W.T.
LIGHT CLAYEY SOIL
GRAIN SIZE DISTRIBUTION
DEPARTMENT OF CIVIL ENGINEERING
U. OF A.
4 FEB. 1949
% FINER THAN
GRAIN SIZE mm.
SIZES
INTERNATIONAL
CLAY
SILT
SAND
GRAVEL
0·0001
0·001
0·01
0·1
1·0
10

FIG.15

SAMPLE NO. 5

This sample was taken from an area close to where sample No. 4 was obtained. The area had not however been stripped of vegetation and frost was about sixteen inches from the surface. Sample was taken from twelve to twenty-four inches in depth. The material in the area is of glacial origin.

The following pertinent data was determined:

Sample Taken	- July 31st, 1948.
State	- Partially frozen, undisturbed.
Moisture Content	- 16.0% to 51.3% Average 31.1%
Specific Gravity	- 2.73
Average Plastic Limit	- 22.9%) See Fig. 16
Plasticity Index	- 4.6) See Fig. 16
Liquid Limit	- 27.5%
Grain Size	- See Fig. 17
Triaxial Compression Tests	- See Figs. 18 and 19

This sample when compared with No. 4 shows up markedly the great reduction in moisture content which occurs as the permafrost is thawed and the segregated ice is melted. The other properties of the soil are almost identical with those of Sample No. 4.

Triaxial compression tests were run on the frozen portion of the specimen and the results are illustrated in Figs. 21 and 22. Failure of the frozen specimens was generally a plastic compression rather than

(Sample No. 5 - cont'd)

a shear failure although shear planes could be seen on the broken specimen. The high strength of frozen soil is well illustrated on the stress strain curve. Soil tests were run at temperatures from -2° to -10° C.

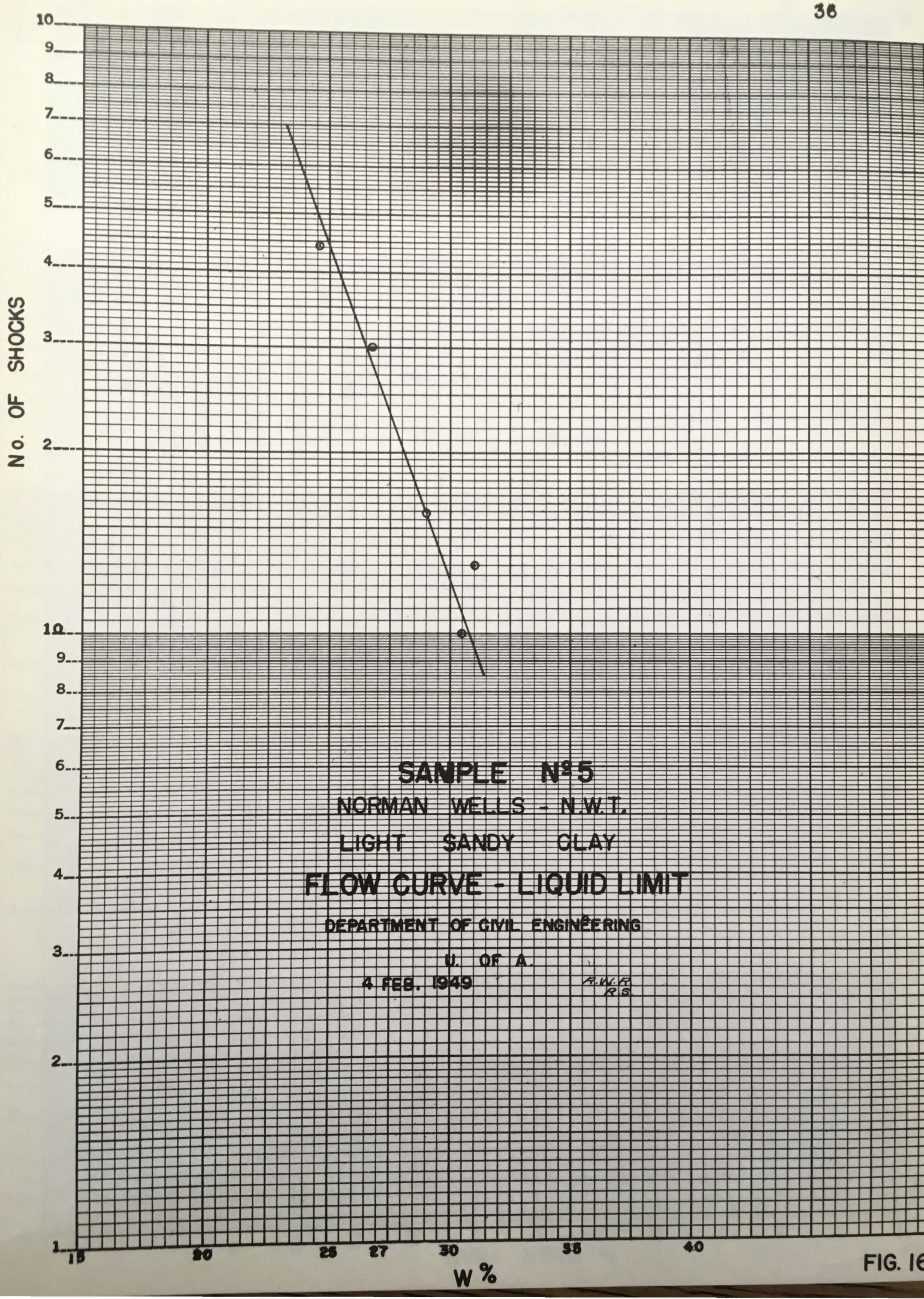

SAMPLE Nº 5
NORMAN WELLS - N.W.T.
LIGHT SANDY CLAY
FLOW CURVE - LIQUID LIMIT
DEPARTMENT OF CIVIL ENGINEERING
U. OF A.
4 FEB. 1949
R.W.R.
R.S.
No. OF SHOCKS
W %
10
9
8
7
6
5
4
3
2
1
15
20
25
27
30
35
40

FIG. 16

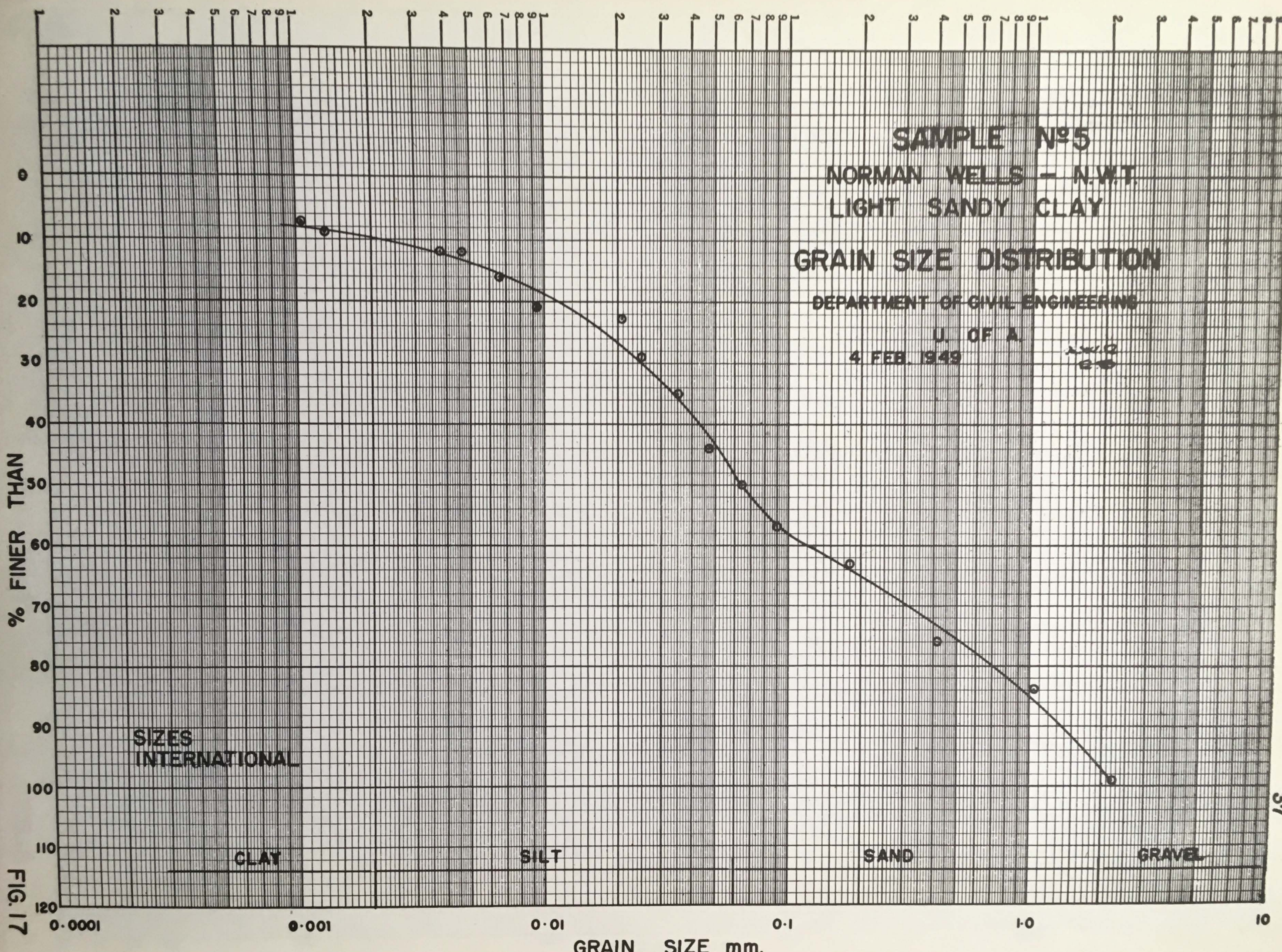
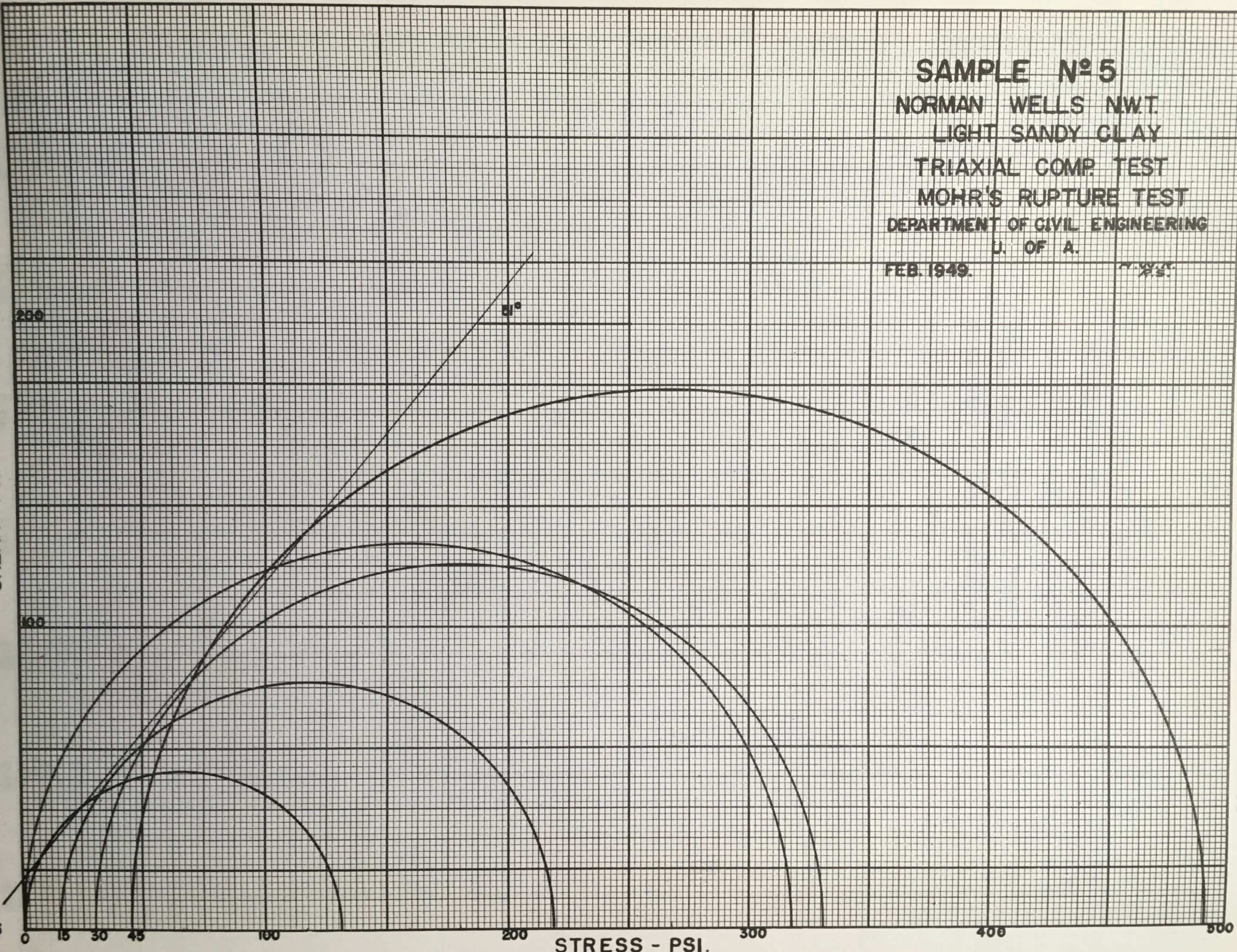

SAMPLE Nº 5
NORMAN WELLS - N.W.T.
LIGHT SANDY CLAY
GRAIN SIZE DISTRIBUTION
DEPARTMENT OF CIVIL ENGINEERING
U. OF A.
4 FEB. 1949
SIZES
INTERNATIONAL
CLAY
SILT
SAND
GRAVEL
% FINER THAN
0
10
20
30
40
50
60
70
80
90
100
110
120
0·0001
0·001
0·01
0·1
1·0
10
GRAIN SIZE mm.

FIG. 17



SAMPLE Nº 5
NORMAN WELLS N.W.T.
LIGHT SANDY CLAY
TRIAXIAL COMP. TEST
MOHR'S RUPTURE TEST
DEPARTMENT OF CIVIL ENGINEERING
U. OF A.
FEB. 1949.
51°
200
100
SHEAR - PSI.
15
0
15
30
45
100
200
300
400
500
STRESS - PSI.

FIG. 18.

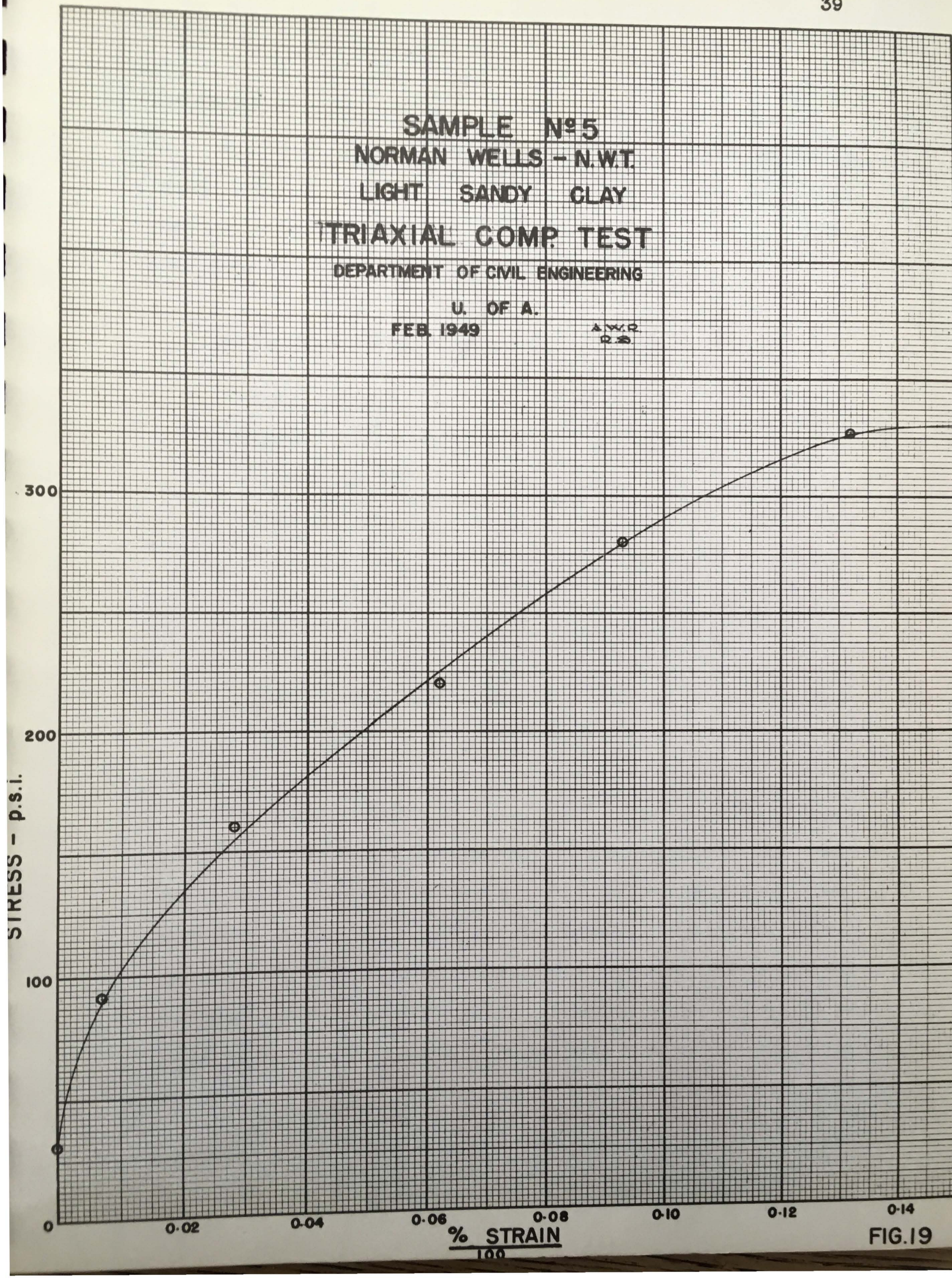

SAMPLE Nº 5
NORMAN WELLS - N.W.T.
LIGHT SANDY CLAY
TRIAXIAL COMP. TEST
DEPARTMENT OF CIVIL ENGINEERING
U. OF A.
FEB. 1949
STRESS - p.s.i.
0
100
200
300
0.02
0.04
0.06
0.08
0.10
0.12
0.14
% STRAIN
100

FIG. 19

SAMPLE NO. 6

This sample was taken from a low wet area where the permafrost was always close to the surface. Brush had been cleared away, but the moss was left intact. Frost was out to a depth of eighteen inches. Sample was taken at a depth of eighteen inches to thirty inches.

The following data has been determined:

Sample taken	- August 2nd, 1948.
State	- Frozen, undisturbed.
Moisture Content	- 260 to 296%
Specific Gravity	- 2.17
Shrinkage Limit	- About 64.7% - values were scattered.
Plastic Limit	- Plastic Limit not obtainable but is greater than Liquid Limit - See Fig. 30
Liquid Limit	- 97%
Grain Size	- See Fig. 21

This is another sample of the silt with large inclusions of segregated ice. The results indicate that it is a very unusual soil from the point of view of soil mechanics. The high moisture content shows to what an extent ice is present in the material. The various limit tests are inconclusive, several scattered values were obtained for the shrinkage limit test--and the plastic limit was not obtainable. It was greater than the liquid limit. The very high value for the liquid limit

(Sample No. 6 - cont'd)

would indicate a highly compressible soil. This can be explained by the high vegetable content.

The grain size curve shows very well the type of soil being dealt with.

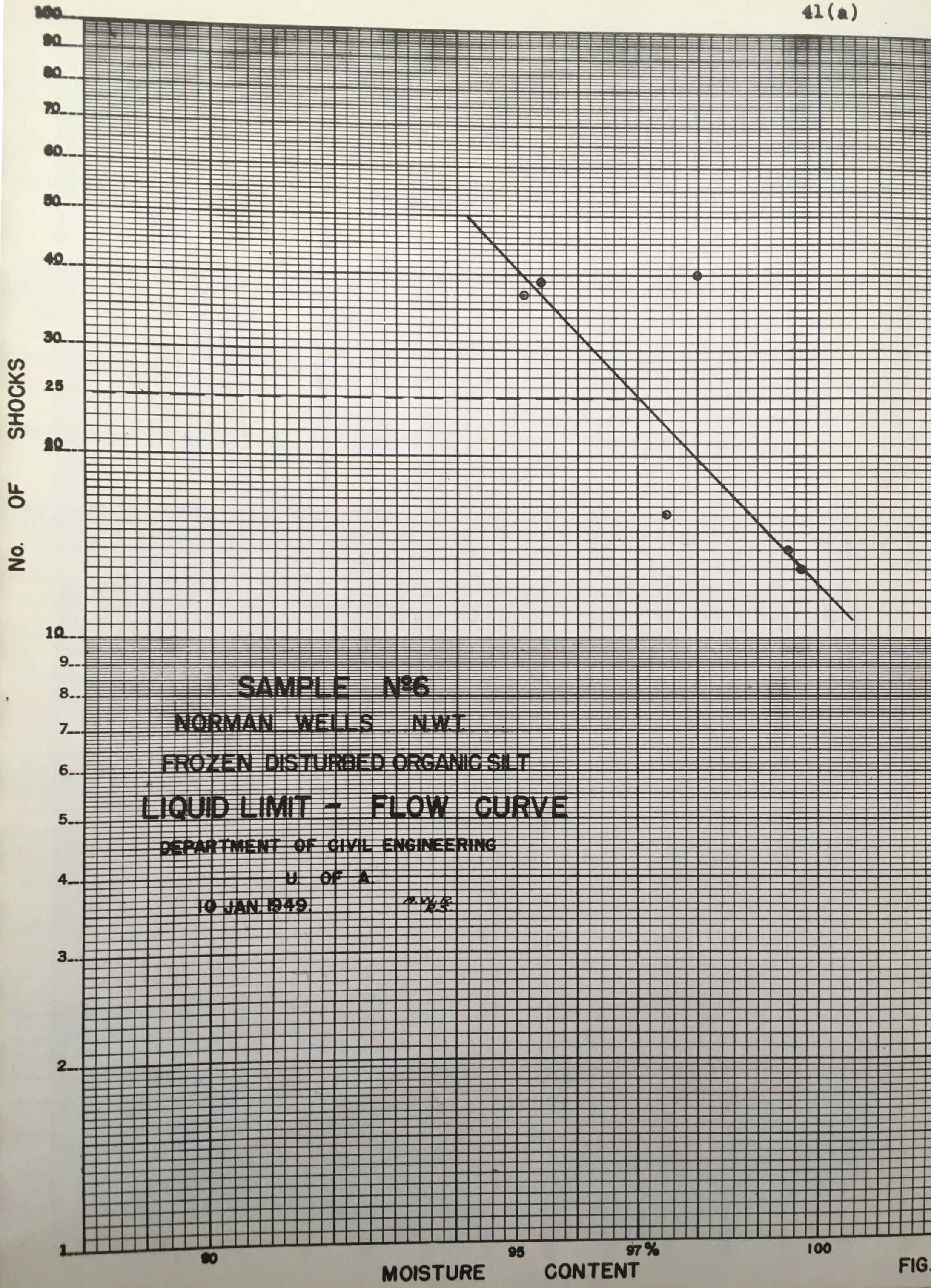

SAMPLE Nº6
NORMAN WELLS N.W.T.
FROZEN DISTURBED ORGANIC SILT
LIQUID LIMIT - FLOW CURVE
DEPARTMENT OF CIVIL ENGINEERING
U. OF A.
10 JAN. 1949.
No. OF SHOCKS
MOISTURE CONTENT
100
90
80
70
60
50
40
30
25
20
10
9
8
7
6
5
4
3
2
1
90
95
97%
100

FIG. 20

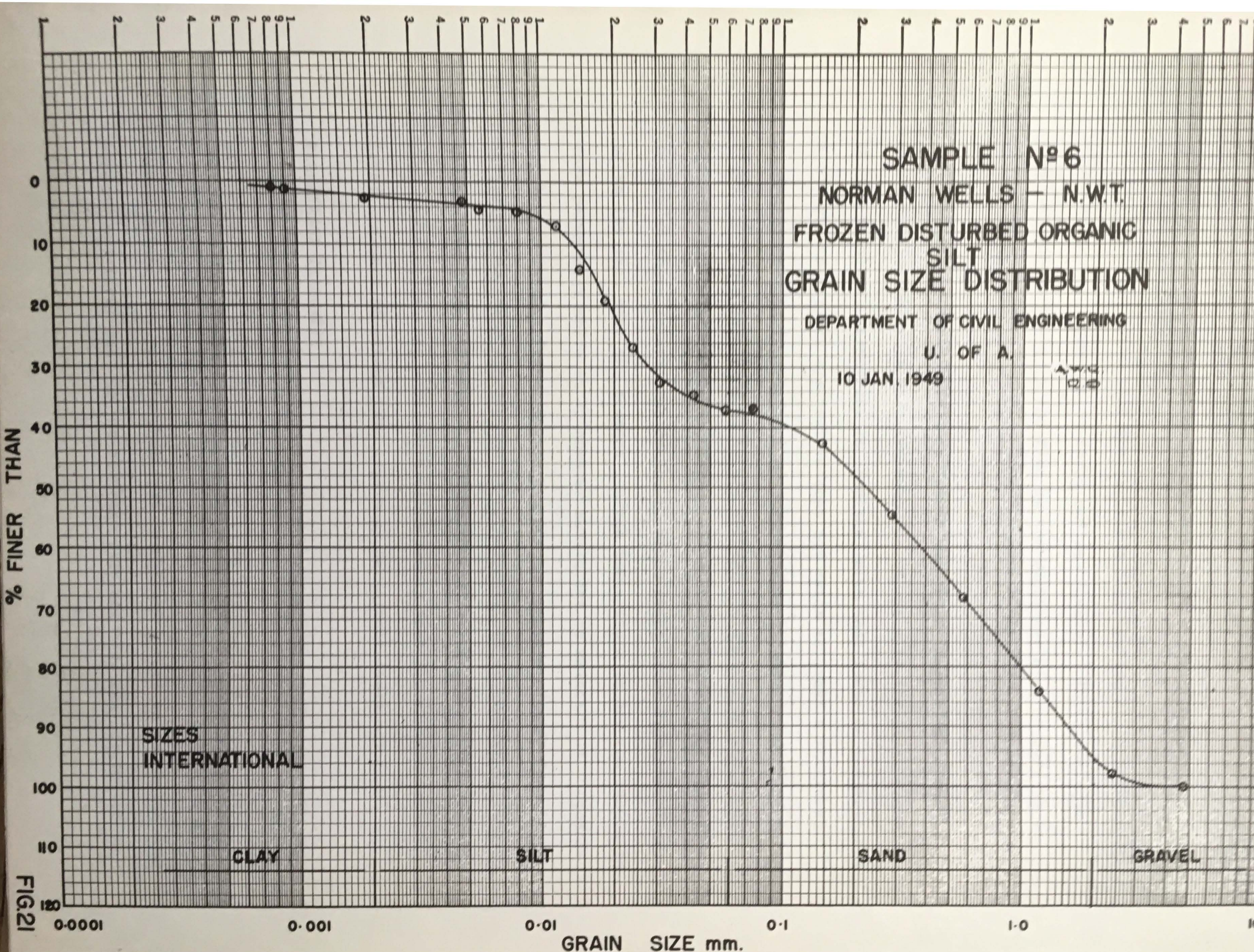

SAMPLE Nº 6
NORMAN WELLS - N.W.T.
FROZEN DISTURBED ORGANIC SILT
GRAIN SIZE DISTRIBUTION
DEPARTMENT OF CIVIL ENGINEERING
U. OF A.
10 JAN. 1949
% FINER THAN
GRAIN SIZE mm.
0·0001
0·001
0·01
0·1
1·0
10
SIZES INTERNATIONAL
CLAY
SILT
SAND
GRAVEL

FIG.21

PERMAFROST DISTRIBUTION

It has been found that the depth and distribution of permafrost is effected by the presence of large bodies of water. The permafrost level at Norman Wells is modified by the Mackenzie River according to record of temperature at depth.

In certain sandbar islands in the Mackenzie, permafrost does not exist at all, while in silt islands, i.e. those with the stratigraphy of the mainland, permafrost is identical with that found on the mainland although indications are that it does not reach as great a thickness. It is interesting to note that on some sandbar islands, poplar and white birch trees are developed up to six inches in diameter, so that these islands have existed several years. The fact that permafrost has not formed on these islands may be due to percolating water from the river, or to the fact that the present average temperature is not low enough to form permafrost while it is however sufficient to maintain it. According to published information, an average temperature of +22° F would be sufficient to cause aggradation of permafrost. It is however difficult to understand how the river could modify soil temperatures in an island some three miles long and rising up to twenty feet above normal river level, to such an extent that layers of permafrost could not form.

PERMAFROST THICKNESS

The depth to which permafrost has formed is always of great interest in the study of Arctic conditions. By the use of a slow reading thermometer several observations were taken in abandoned oil wells at Norman Wells. The results show that permafrost occurs to depths of one hundred and forty feet to two hundred feet (see Fig. 22), depending on

the locale. This does not agree with reports of W. A. Johnston.[1] The holes had however been abandoned for two to three years, were plugged and inactive, and there should be little chance of error due to convection or conduction of heat by the tubing, especially since the temperature gradient is very low. Several check readings were taken and all results checked well.

The use of a slow reading thermometer was tedious and difficult but it was the only equipment available at the time which could be adapted to use in wells under pressure. A sketch, Fig. 23, shows how a bomb was made and how the insulated thermometer was bedded in paraffin.

These thicknesses of permafrost check also with drilling experience at Norman Wells which has shown freezing in of casing and poor cement jobs to depths of about two hundred feet.

It is interesting to note the increasing thickness of permafrost as the distance from the river increases. Well Imperial #17X is located some three hundred feet from the river and the permafrost thickness is about one hundred and forty feet. Wells 15X and 33X are about twelve hundred and a thousand feet respectively from the river channel. Well No. 15X is on the bank of a small stream which runs year round and might effect the permafrost depth appreciably.

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1 – "Frozen Ground in the Glaciated Parts of Canada". Royal Society of Canada, Tr. Ser. 3, Vol. 24, Sec. 4 Pages 31-40 by W. A. Johnston (1930)

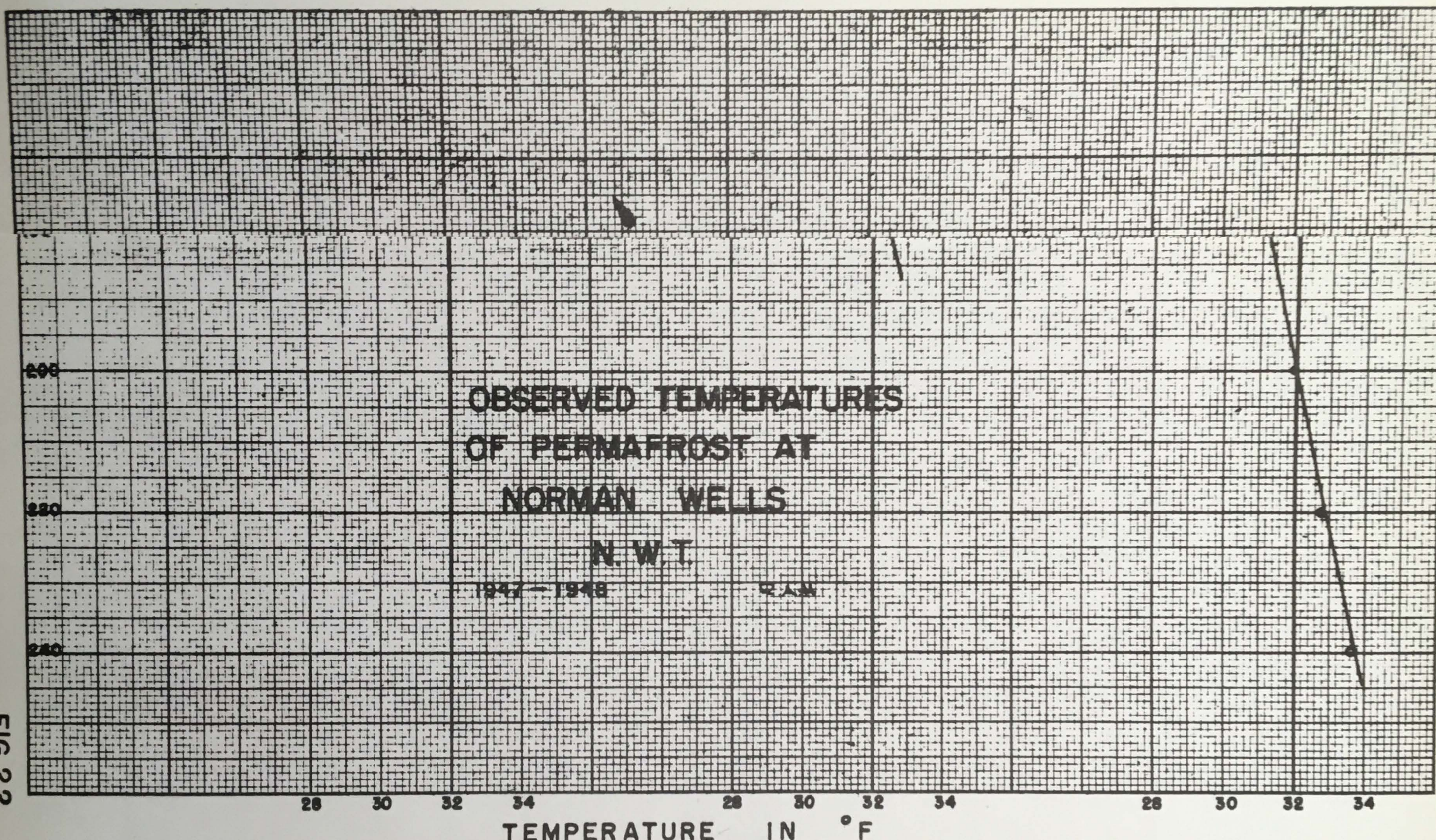

OBSERVED TEMPERATURES
OF PERMAFROST AT
NORMAN WELLS
N. W. T.
1947 — 1948
28
30
32
34
28
30
32
34
28
30
32
34
TEMPERATURE IN °F

FIG. 22

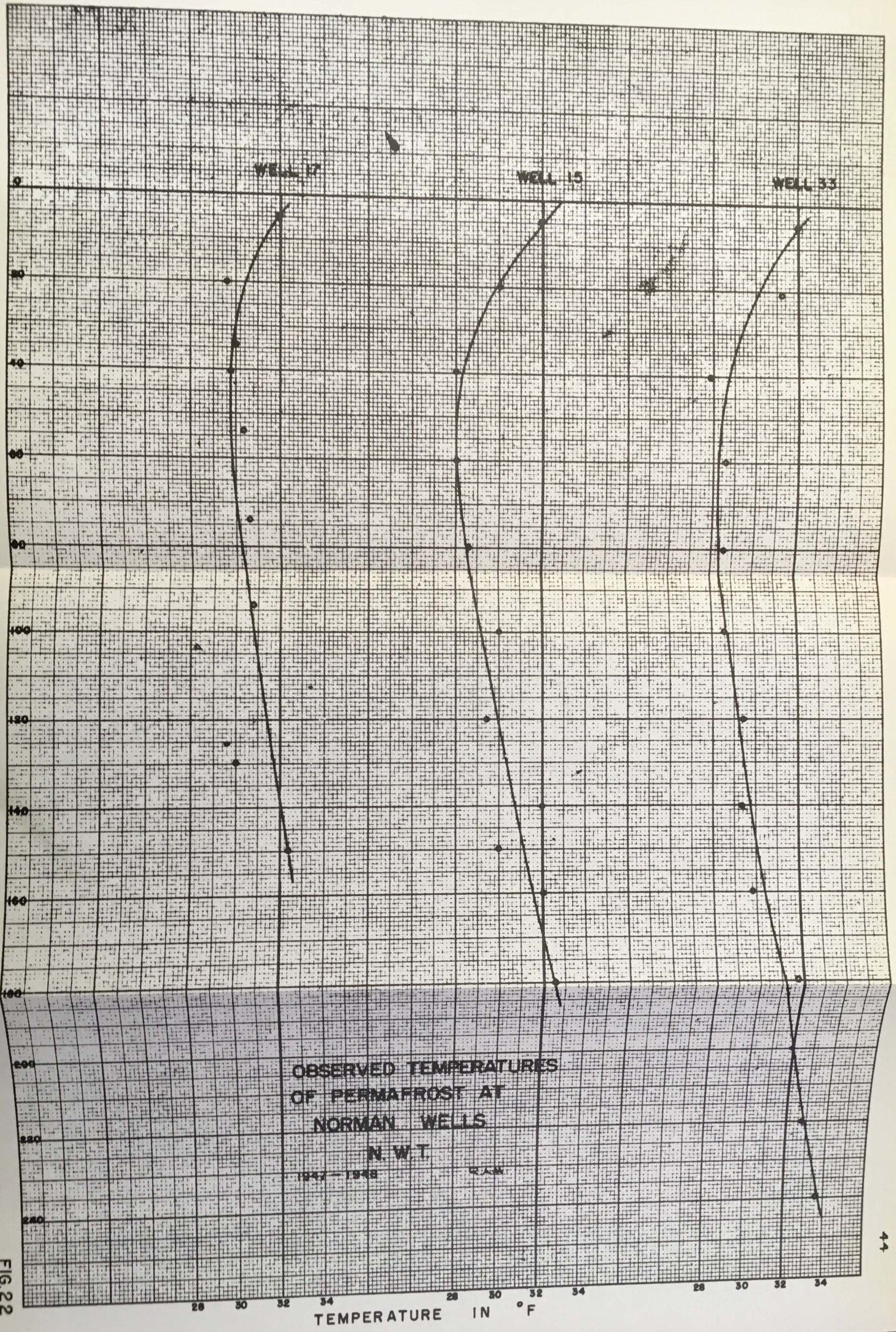
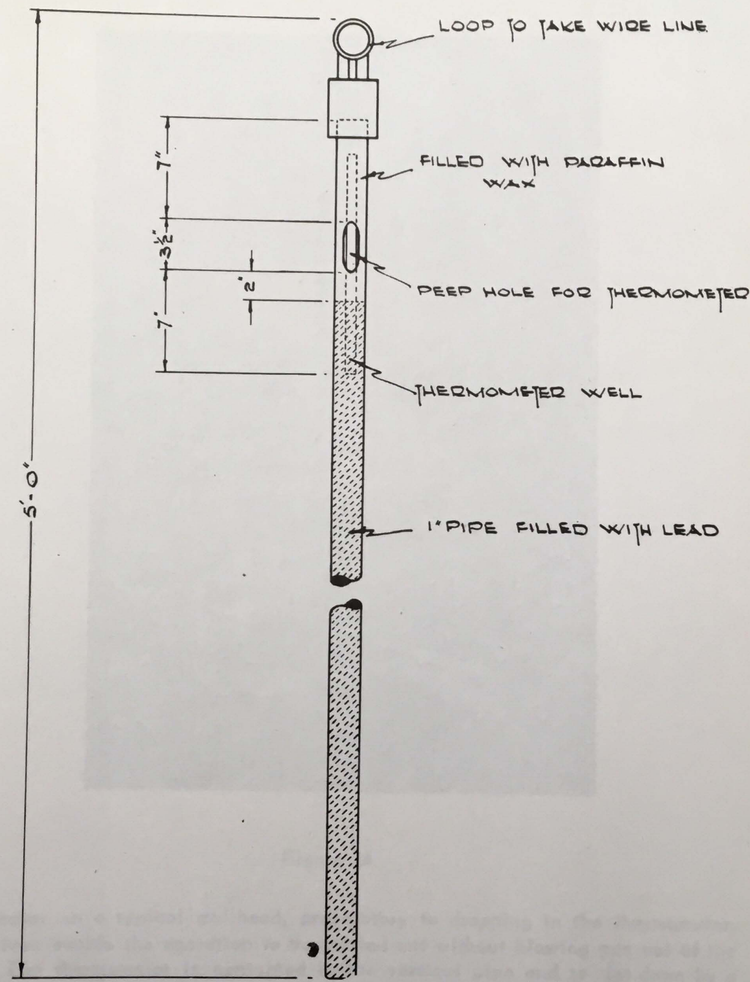

OBSERVED TEMPERATURES
OF PERMAFROST AT
NORMAN WELLS
N.W.T.
1947 - 1948
R.A.W.
WELL 17
WELL 15
WELL 33
DEPTH IN FEET
TEMPERATURE IN °F
0
20
40
60
80
100
120
140
160
180
200
220
240
28
30
32
34

FIG.22



TEMPERATURE BOMB FOR WELLS

FIG. 23

Figure 24

Lubricator on a typical wellhead, preparatory to dropping in the thermometer. The valves enable the operation to be carried out without blowing gas out of the well. The thermometer is contained in the vertical pipe and is let down by a wire line run over the pulleys.

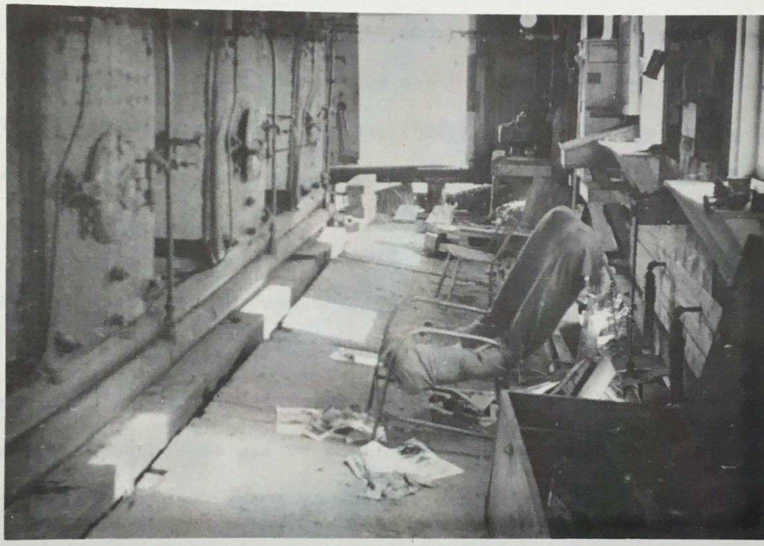


Figure 25

A picture showing how thawing of permafrost has caused settlement of the floor of a boiler house. The floor was originally level with the top of the door sill upper centre, and has dropped about 20". The boilers are on concrete blocks on piles and have not moved a great deal. The piles were only driven about three feet in permafrost which had been forced to a depth of about eleven feet by the first boiler plant erected on the site.

CHAPTER III

BUILDING DIFFICULTIES

From the description of the permafrost conditions at Norman Wells, it is obvious that ordinary foundations would be unsatisfactory. High moisture contents make heaving a constant trouble in the winter and in summer whole building sites turn to mud and water. Past experience has shown too that it is much better to design to "get along" with permafrost and its associated conditions than to try to design strong enough to overcome the natural forces.

Until the last great war, there were few requirements for large structures in the North, and the small cabins and houses were founded with little difficulty on the surface in better drained areas. The first large expansion occurred at Norman Wells during the war when the Canol Project was begun. It was in this emergency that many buildings were erected--without due regard to foundations. In most cases a fill of silt and dirty gravel--from one to three feet thick was run over the muskeg, and on this were put the pads and posts for the frame buildings. A small town was erected in this manner--the only variations being that in shops and power plants a slab of concrete was poured for the floor directly on the fill.

The first six months after construction proved that permafrost must be dealt with in a different manner. Heat from the buildings caused settling of the interior of the buildings. That is the permanently frozen ground was gradually thawed and due to its very high water content settling was inevitable--the four inch concrete floor of the camp boiler house settled thirty inches in the first winter. See Fig. 25.

At the same time these conditions led to a large supply of water under the building, which was easily available for frost heave around the circumference of the building. Differential movement of fourteen inches in ordinary living quarters was recorded in six months.

Attempts were made during the second summer after erection to shim up the buildings in the hope that equilibrium had been reached, and that further settlement would not occur. However, frost heaving around the outside of the building of course continued and measurements showed too that settlement under heated buildings also went on although at a reduced rate. A total of fifty-two inches settlement under the locomotive type heating boilers was recorded in the two years after construction.

In 1943 several important installations were made at the field--among them the erection of two repressuring stations. The heavy reciprocating machinery and high pressure piping required substantial foundations that would not be subject to heaving or settling. Test pits sunk at the locations selected showed the soil to be a typical fine silty material with inclusions of segregated ice. Layers of clay and some gravel were encountered below twelve feet. A weak sandstone bedrock occurred at about forty feet. No machinery was available to carry the foundations to bedrock, so it was decided to drive wooden piles well into the permafrost--to insulate around the tops of the piles and to pour concrete blocks founded on the piles. The active layer was taken off and work was carried on at the original top of the permafrost to give better drainage of the final job--and to allow greater pene-

tration of the piles. Examination of this foundation after four years-the building was heated for the first eighteen months and unheated after that--showed no measurable movement, and no visible deterioration of any part of the foundation.

PILE DRIVING

Since 1943 all important construction at Norman Wells has been erected on piles. During this time there has been an opportunity to improve the pile driving methods, to study the behaviour of the piles and generally devise satisfactory engineering methods for the North.

Since the ground is frozen--holes must be jetted out for piles. Experience showed that the most economical method was to use a steam jet--a three-quarter to one inch pipe about one foot shorter than the desired pile depth is used--a steam pressure of fifty to eighty pounds or greater seems most satisfactory. Experience and a careful study of the ground will aid in getting economical results. Some pertinent points for similar conditions are:

1. If the ground has dry layers--some water with the steam will speed jetting.

2. Holes may be left up to three weeks in summer before driving piles, but in freezing weather should not be left more than a week.

3. Except in large gravel--special bits, e.g. chisel bit--did not speed jetting.

4. Under favorable conditions, one man can steam jet up to twenty-five, sixteen foot holes in an eight hour day.

5. Best results are obtained when a hole is jetted just big enough to take the pile. With experience on different ground types, and care in jetting, this may be easily accomplished.

Several types and sizes of drop hammers and air hammers were tried. For the particular type of driving required, that is light driving to a depth of about sixteen feet, it was found that a light, fast drop hammer outfit mounted on a small crawler type tractor was most satisfactory. Piles could be quickly and easily handled and driven to refusal in the least possible time. Moreover the machine could move fairly well in the wet, soft ground. With this outfit, two men can drive up to thirty wood or steel piles in eight hours.

For the first construction with piles, wood was used exclusively and because of high shipping costs on imported timber, native spruce was chosen. Piles were from seven to ten inches at the top--driven butt down to help prevent heaving. Some were driven with the asphalt treated paper "collars" as recommend by Muller[1], while no treatment was given others. To date none driven twelve feet or more with asphalt collars,

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1 _ "Permafrost or Permanently Frozen Ground and Related Problems". by S. W. Muller - Page 96

and none without asphalt covers with penetration of over fifteen feet, have shown any sign of heaving.

HEAVING OF PILES

The actual process of heaving as encountered in piles or poles should perhaps be explained more fully. Under normal conditions, a pile is jetted into permafrost and upon completion of the driving, freezing back of the permafrost begins almost immediately at Norman Wells. This freezing serves to anchor the pile in place and prevent any further movement. However when surface frost begins to form in the active layer, it adheres to the surface of the pile--and upon freezing of the ground and the resultant heaving, an upward force is exerted on the pile. The forces on the pile then are the upward force of the frost heaving while those resisting this movement are the weight on the pile plus the anchorage in permafrost. If the anchoring is not strong enough, the pile will heave and failure will result.

Piles have heaved up to eight inches in one season where they were not driven far enough into the permafrost for adequate anchorage. As would be expected, this heaving was most noticeable in low, wet areas--while in higher, well drained locations scarcely any heaves have been recorded. As indicated in Fig. 37, frost heaves of piles may be cumulative resulting in movements of twenty or thirty inches in a few years. The rule of thumb recommended by Muller that pile penetration of permafrost be twice the active layer seems to be satisfactory in all cases at Norman Wells. The use of asphalt "collars" should not be considered as the final word in preventing frost heave, since the collars them-

selves are only in good condition for one or two seasons. They are however very useful in getting past the first season when the permafrost anchoring may not be completed, (i.e. the permafrost table has not been re-established to its final level). If steel piles are used, a more satisfactory method is the provision of a collar or flange at the base of the pile which freezes in first of all and will prevent heaving almost immediately.

With these precautions it is not difficult to secure good foundations no matter what time of the year the work is being done. Foundations have been successful at Norman Wells under even the worst conditions in every month of the year. Freezing in is of course much more rapid than that mentioned by Muller. See Fig. 33.

PILE MATERIALS

In all construction over the past year and a half, steel piles have been used exclusively, for purely economic reasons. They were available at no cost from scrap pipe, were more easily handled and driven than were wooden piles, and they are slightly flexible as to position after driving. They may be quickly and cheaply lengthened, cut or capped by welding. So far none driven fifteen feet or more have heaved or settled under normal conditions, and examination of foundations erected for two years indicate that they should be very satisfactory. To prevent heaving, collars one and a half inches greater in diameter than the pipe were welded or screwed to the butt of the pile. Pile spacing may be varied to suit the type of construction--in light frame buildings, it varied from six to ten feet to fit sill spacing

Figure 26

A typical installation of steel piles. The building is well off the ground which has been left protected by the moss cover. Frost was without 12" of the surface beneath this unheated building.

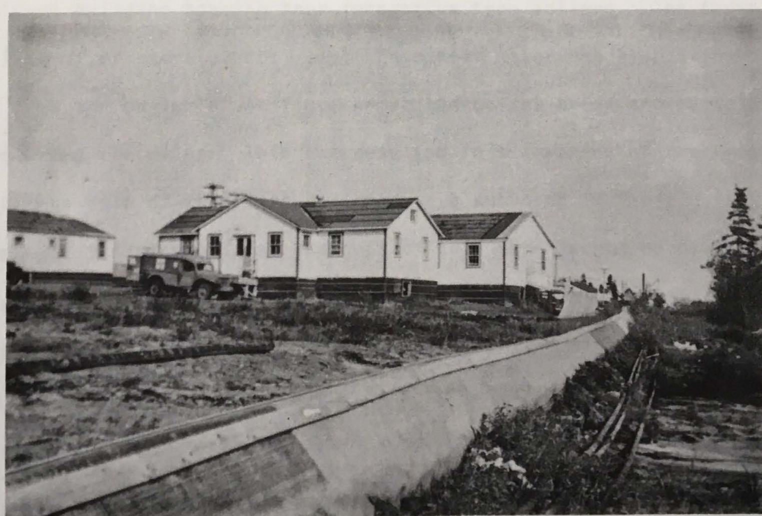


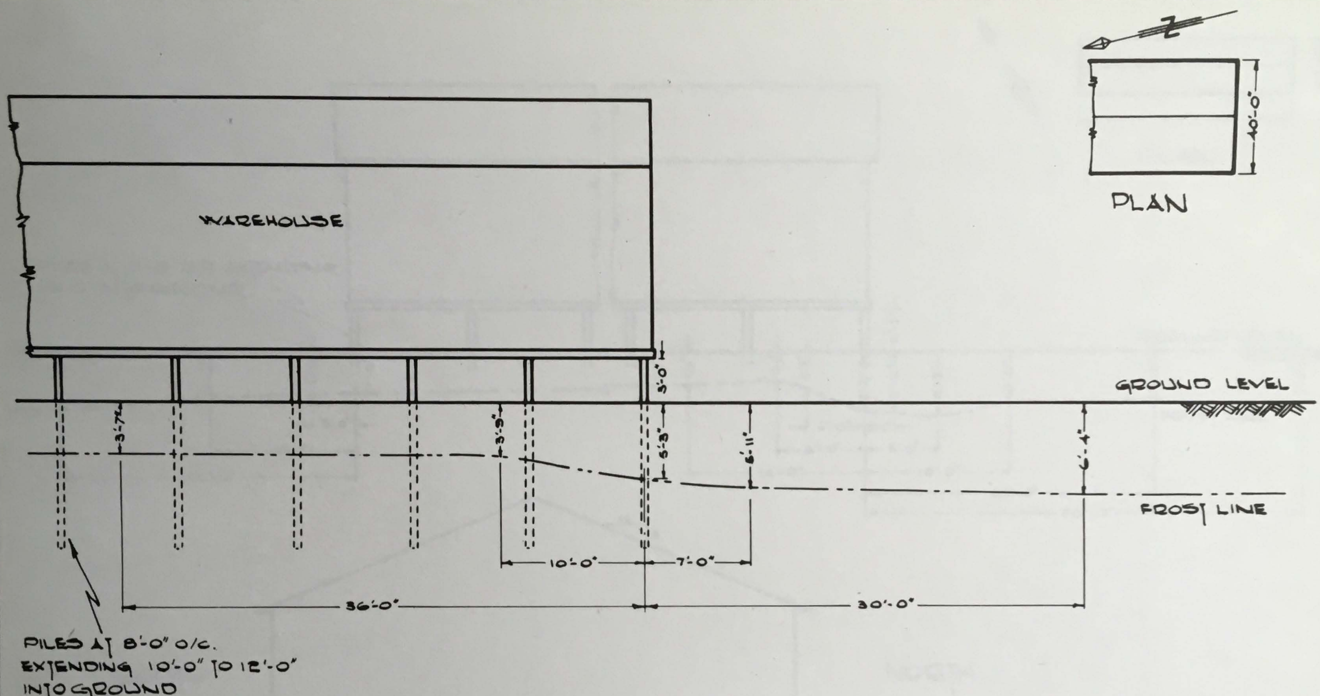
Figure 27

Here we see the building set on piles with the piles "skirted in" to protect the floors from the cold. Note the vent doors which should be left open in summer to help cool the area under the floor and prevent lowering of permafrost.

and joists. In spacing piles closer than three feet on centre, greater care must be taken in steam jetting holes to prevent complete thawing of the ground and the consequent long refreezing period.

Wherever possible, the piles are extended eighteen to twenty-four inches above the surface of the ground, and the building then erected, thus allowing a clear space under the building for air circulation so that the permafrost level is maintained fairly close to the surface. See Figs. 26, 28 and 29. Figs. 28 and 29 show very well the rise in the permafrost table which occurs when the surface of the ground is protected from the sun. The buildings were unheated and the average air temperature under them seemed to be about 3o F lower than average air temperature in the open. See Fig. 35.

Some settling has occurred in the present boiler house at Norman Wells--a building housing four locomotive type boilers. The fault here is lack of maintenance entirely. Warm wash water has been allowed to run from the boiler house floor under the boiler house and percolate down along the piles. This has resulted in a lowering of the frost line until the base of the piles no longer are anchored in frost. The importance of drainage in an instance of this type cannot be overstressed--moreover the addition of any quantity of heat no matter what its source will result in a dangerous lowering of frost line with disastrous results. It should be pointed out here too that foundation failure does not require the permafrost level dropping below the pile base. Frost heaving such as occurs each winter will heave those piles which are no



FROST LINE VARIATIONS UNDER UNHEATED BUILDING

22 AUGUST 1947

FIG. 28

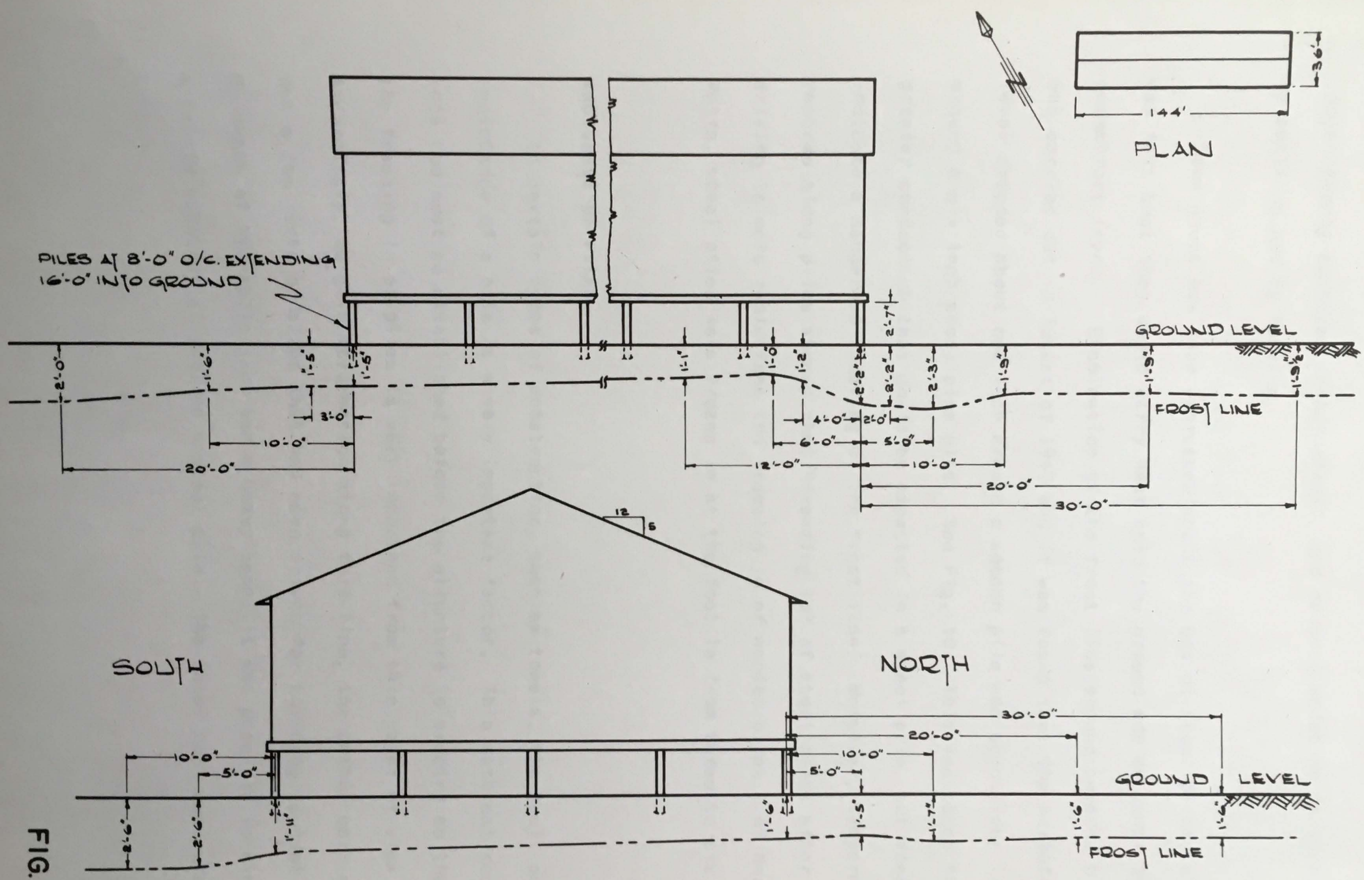


FIG. 29

FROST LINE VARIATIONS UNDER UNHEATED BUILDING

30 JULY 1948

longer firmly anchored in permafrost, and cause foundation failure not by settling but by heaving.

Some doubt has been expressed about the use of steel piles, as it was felt that they would carry heat into the ground and so lower the permafrost level. Examination of the frost line around several piles was carried out in August of 1947 and it was found that the permafrost level dropped about one inch around a wooden pile and about four inches around a six inch steel pipe pile. See Fig. 30. This indicated the greater conduction that could be expected in a steel pile, but does not indicate a dangerous lowering of the frost line. Moreover, temperature records along piles showed that "freezing in" of steel piles after driving is more rapid than the freezing in of wooden piles. At Norman Wells, steel piles were frozen in at the foot in from three to six days.

ANCHORAGE OF PILES

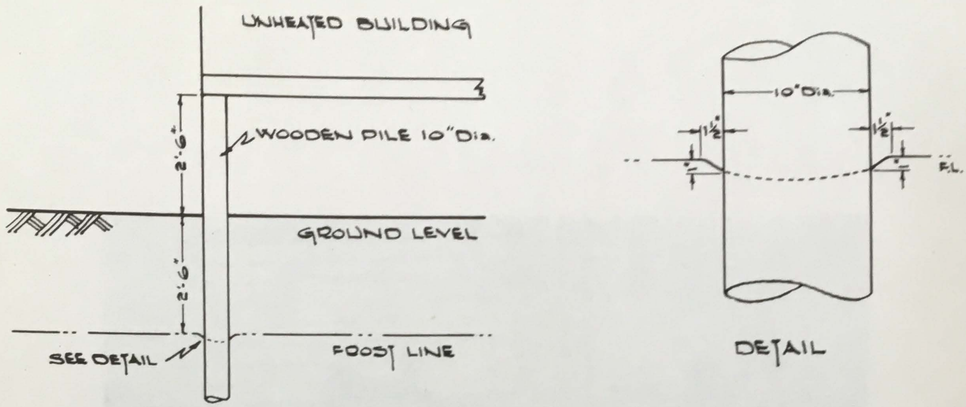
In certain types of construction, such as towers, the "pull out" resistance of a pile is a very important factor. This upthrust resistance too must be established before the structure is erected so that the freezing in of piles is very important from this point of view. Accordingly, to gain information along this line, the author carried out a few tests on piles that had been driven for building foundations. By means of hydraulic jack and a heavy beam, it was possible to exert a fairly substantial pull on a steel pile. The total pull was calcu-

lated from gauge pressure on the jack and lever arm lengths.

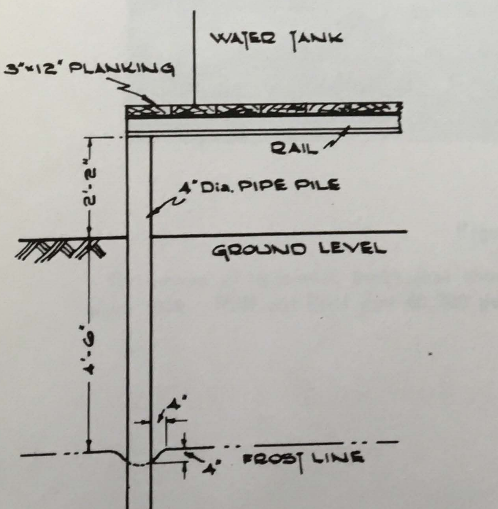
On the first test the pile moved after a pull of 20.1 tons had been exerted. This pile was a straight four inch pipe-driven to sixteen foot penetration. It had been in position for four weeks and was frozen back approximately 3.5 feet at the base. This test result is of course only an isolated case, and other types of soil might not show up so well. It does indicate however, that piles do gain pull out resistance very quickly and should be very useful for this type of foundation, especially if collars or bulbs can be fastened to the base of the pile.

Contours of the frost line under buildings at Norman Wells illustrate very well the effect of different structures on permafrost. Figs. 28 and 29 show how the frostline rises under an unheated building because of the protection from the direct rays of the sun. This effect tends to anchor more fully the piles supporting a structure. It does not however, show up immediately and therefore should not be counted on in the design since it may not be present in the critical period during the first winter when heaving begins.

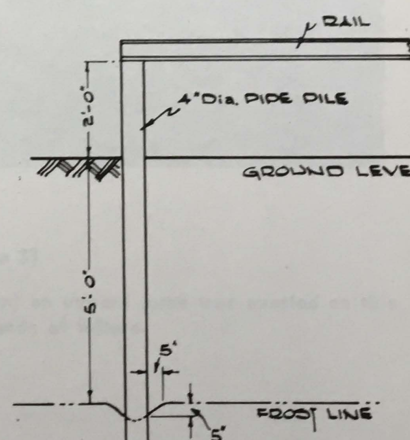
Experiments have been tried with some small buildings, e.g. living quarters twenty-four feet or less in width in which this space under the building is boxed in and the steam and service pipes run in



FROST LINE THROUGH WOODEN PILE
BUILDING UNHEATED
6 SEPT. 1947



FROST LINE THROUGH STEEL PILE
SUPPORTING WATER TANK
15 SEPT. 1947



FROST LINE THROUGH STEEL PILE
SUPPORTING ONLY RAILS
FOR A BUILDING
15 SEPT. 1947

FIG. 30

Figure 31

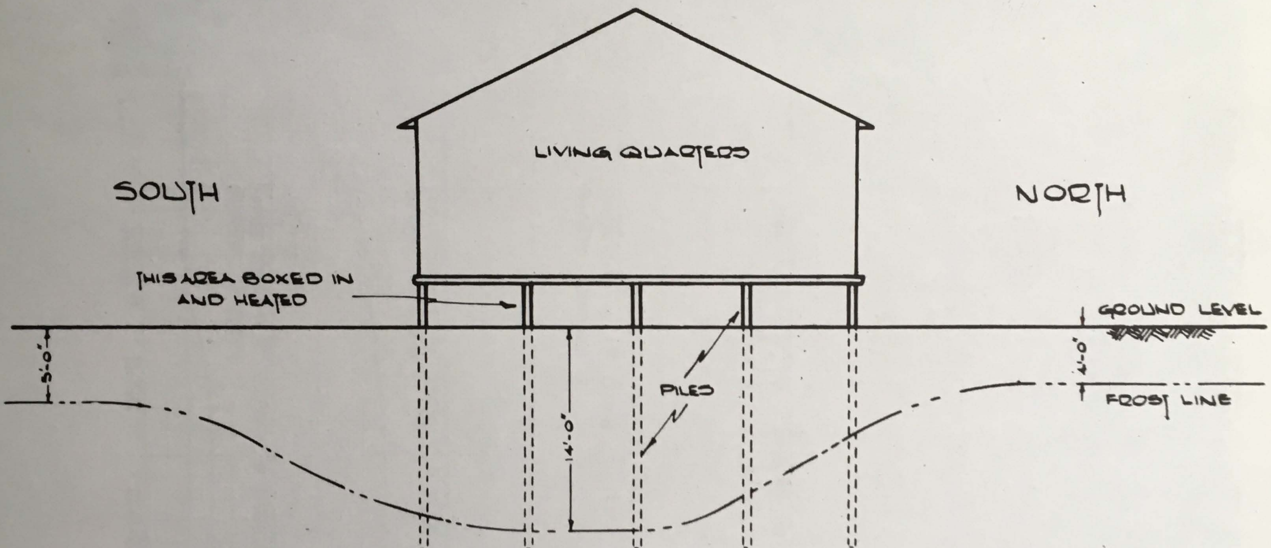
By means of hydraulic jacks (not shown) an upward force was exerted on this pipe pile. Pull out load was 40,200 pounds at failure.

it. This gives very warm floors and uniform heating of the house and seems satisfactory, if the building is narrow enough so that frost coming in from the sides maintains the permafrost level well above the base of the pile.

Fig. 32 shows the effect of a heated building on the frost line. A very sharp recession has occurred and the piles are on the point of failure. This building is one in which the air space under the building had been boxed in to protect the steam lines and promote warm floors. Temperatures in this space ranged from 50° F to 110° F, according to the season. This very high temperature caused the rapid frost line recession--unless this is checked, failure will occur almost at once. In other cases however where the temperature can be held to just above freezing in winter, and kept cool and ventilated in summer the frostline should not be so adversely effected and the foundation would be satisfactory.

In order to check soil temperatures under buildings, readings have been taken over a period of about a year, along piles driven in 1947. From the Fig. 33, we find that the average temperature at depth of sixteen feet under an unheated building appears to be about 28° F. The rapid restoration of the stable soil temperatures indicates that piles driven under these conditions would freeze in relatively quickly. This is borne out by the results shown on page 59.

Some of the graphs show temperatures at relatively shallow depths under heated buildings and indicate recession of permafrost and failure if piles had not extended to a greater depth. They all indicate however, a fairly rapid temperature drop and freezing in of the pile immediately after the driving and before the erection of the building.



FROST LINE BELOW HEATED BUILDING

NO PROVISION FOR HOLDING PERMAFROST LINE UP

FIG. 32

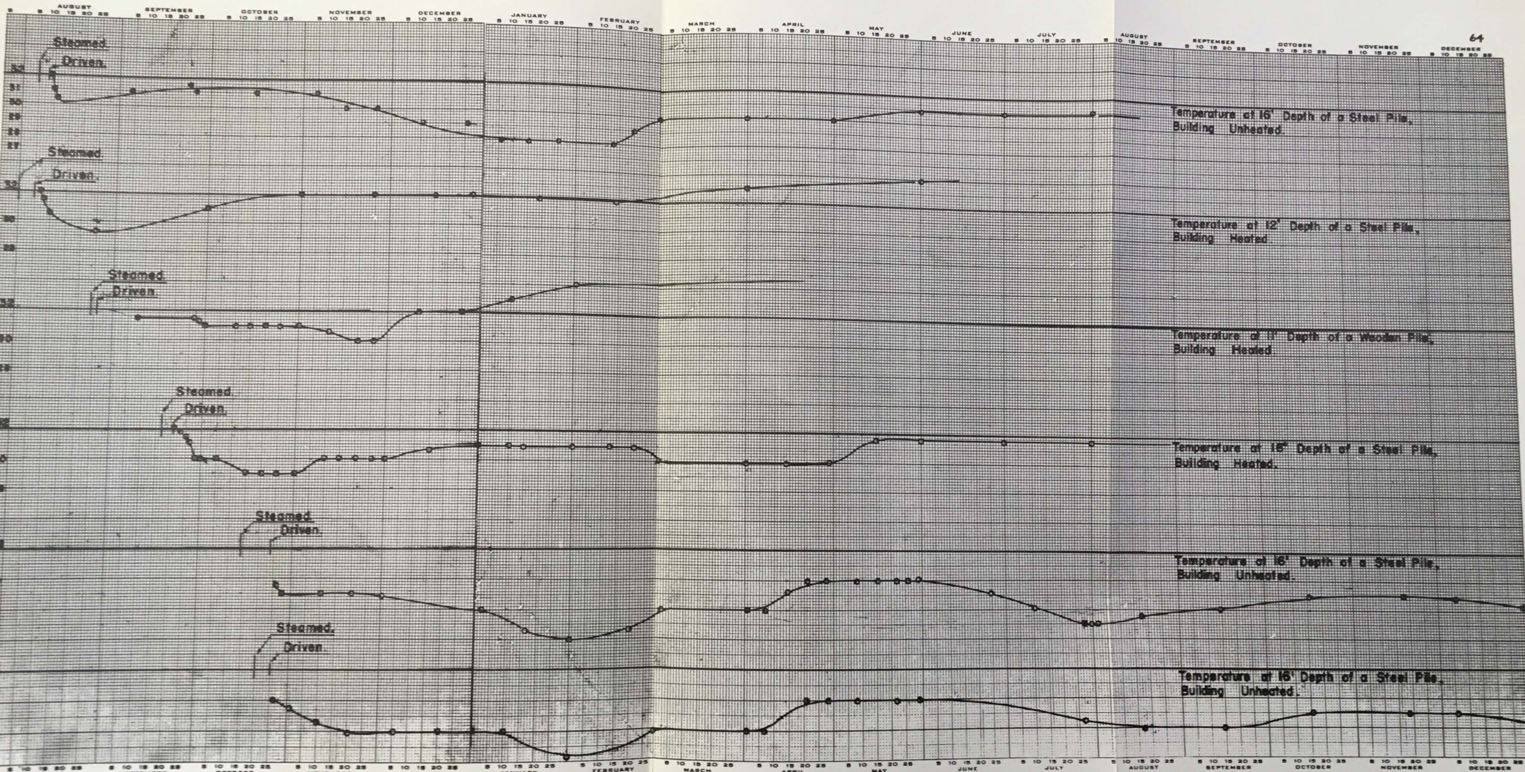

Steamed.
Driven.
Temperature at 16' Depth of a Steel Pile,
Building Unheated.
Temperature at 12' Depth of a Steel Pile,
Building Heated.
Temperature at 11' Depth of a Wooden Pile,
Building Heated.
Temperature at 16' Depth of a Steel Pile,
Building Heated.
Temperature at 16' Depth of a Steel Pile,
Building Unheated.
Temperature at 16' Depth of a Steel Pile,
Building Unheated.
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
1947
1948

FIG. 33

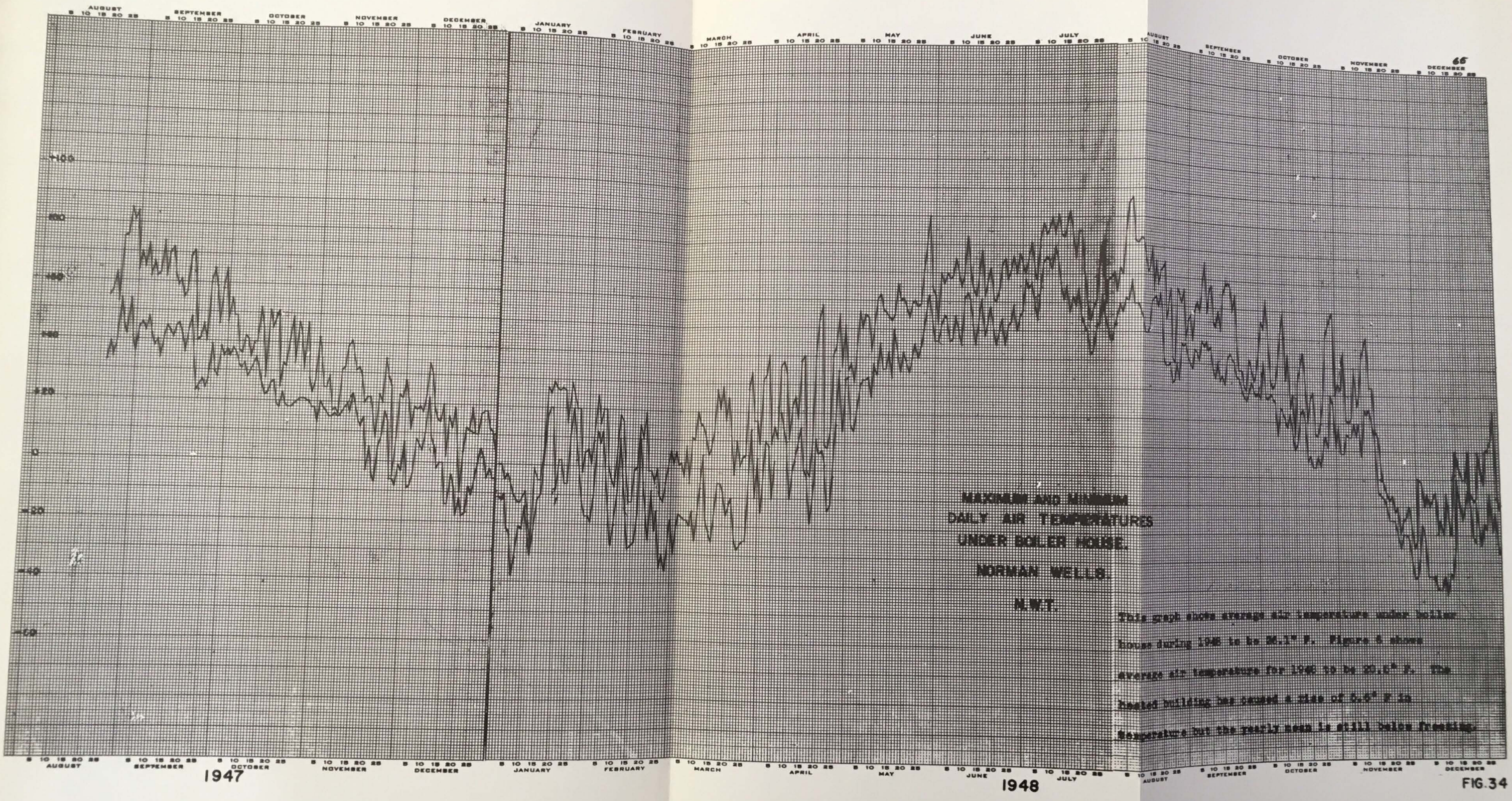

MAXIMUM AND MINIMUM
DAILY AIR TEMPERATURES
UNDER BOILER HOUSE.
NORMAN WELLS.
N.W.T.
This graph shows average air temperature under boiler house during 1948 to be 26.1° F. Figure 6 shows average air temperature for 1946 to be 20.5° F. The heated building has caused a rise of 5.6° F in temperature but the yearly mean is still below freezing.
1947
1948
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
+100
+80
+60
+40
+20
0
-20
-40
-60

FIG.34

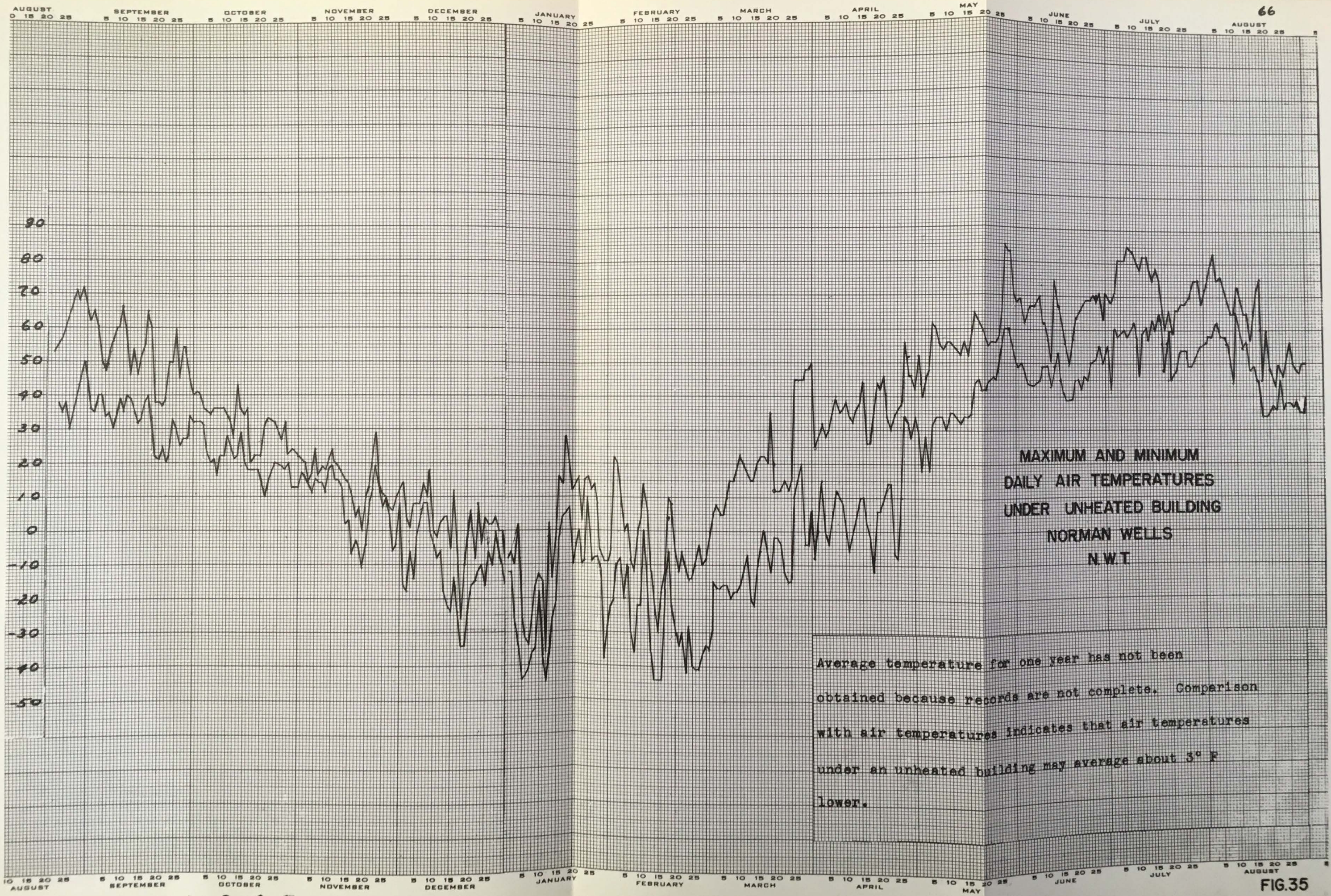
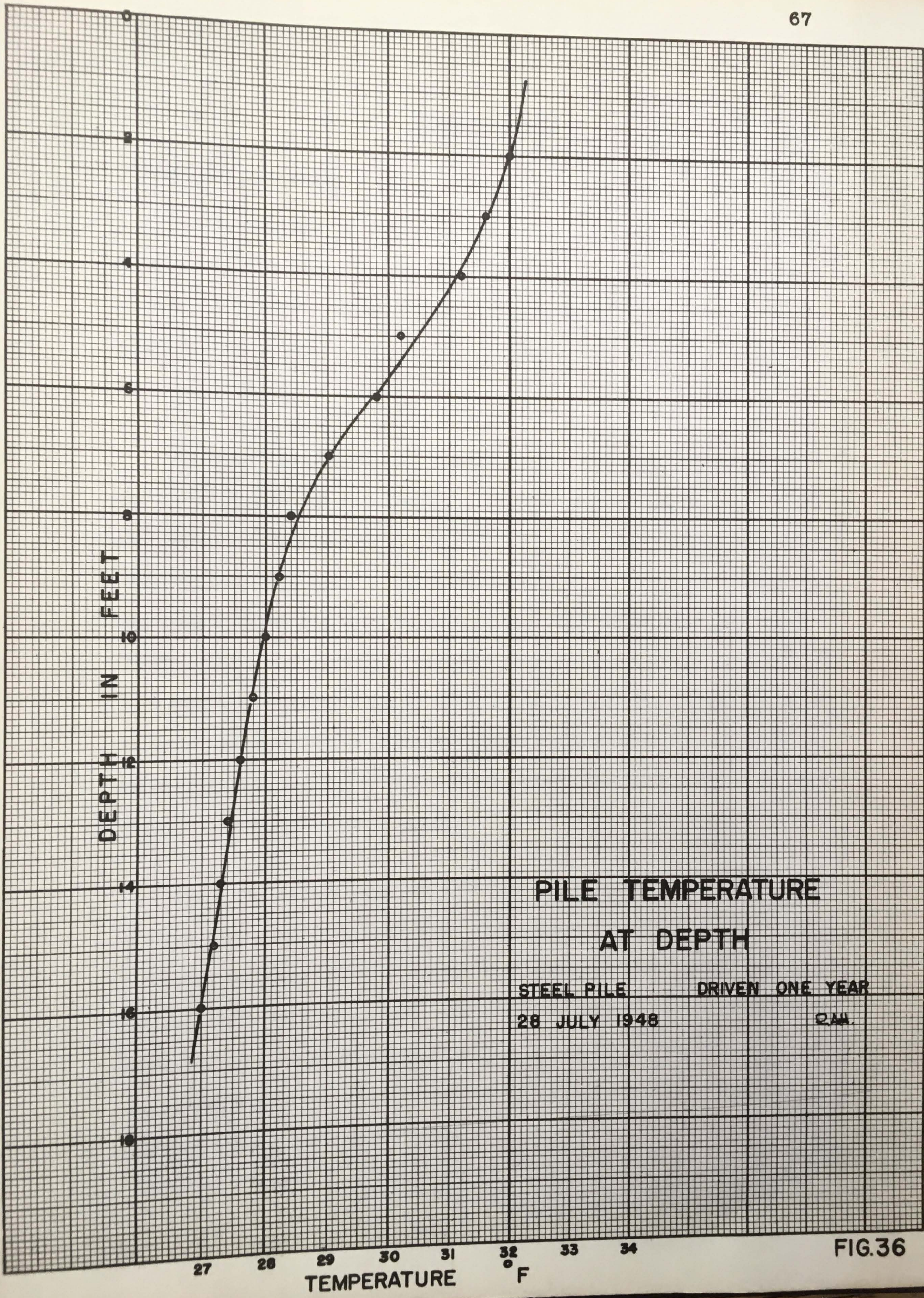

MAXIMUM AND MINIMUM
DAILY AIR TEMPERATURES
UNDER UNHEATED BUILDING
NORMAN WELLS
N.W.T.
Average temperature for one year has not been obtained because records are not complete. Comparison with air temperatures indicates that air temperatures under an unheated building may average about 3° F lower.
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
1947
1948
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50

FIG.35



DEPTH IN FEET
0
2
4
6
8
10
12
14
16
18
27
28
29
30
31
32
33
34
TEMPERATURE °F
PILE TEMPERATURE
AT DEPTH
STEEL PILE
DRIVEN ONE YEAR
28 JULY 1948
2AM.

FIG.36

CHAPTER IV

SERVICE INSTALLATIONS

Another serious engineering problem is the installation of water, sewer and steam lines in locations where the ground is permanently frozen. Difficulty is increased too where the soil has a high water content. It is obvious that buried lines run into high installation and repair costs.

At the Norman Wells site, surface lines have been used almost exclusively although some buried lines were tried. The buried lines did not prove too successful--difficulty was encountered in waterproofing the insulated steam lines which were used to supply steam heat to buildings and at the same time prevented freezing of water and sewer lines. The first surface lines were laid in an insulated box which in turn was supported on logs or short posts driven into the active layer. As would be expected, a great deal of trouble occurred due to movement, especially the heaving of posts which were driven to a maximum of seven feet in the ground. See Fig. 37.

The final method used was to drive single steel piles every seven to nine feet along the line--weld on suitable supports to grade, lay the lines and cover them in with a well insulated box. See Figs. 38 and 39. This method has been very satisfactory--it is not effected by frost heaving, or settlement, repairs are easily and quickly made, and the whole installation can be put in at a fraction of the cost of ditching and laying buried lines.

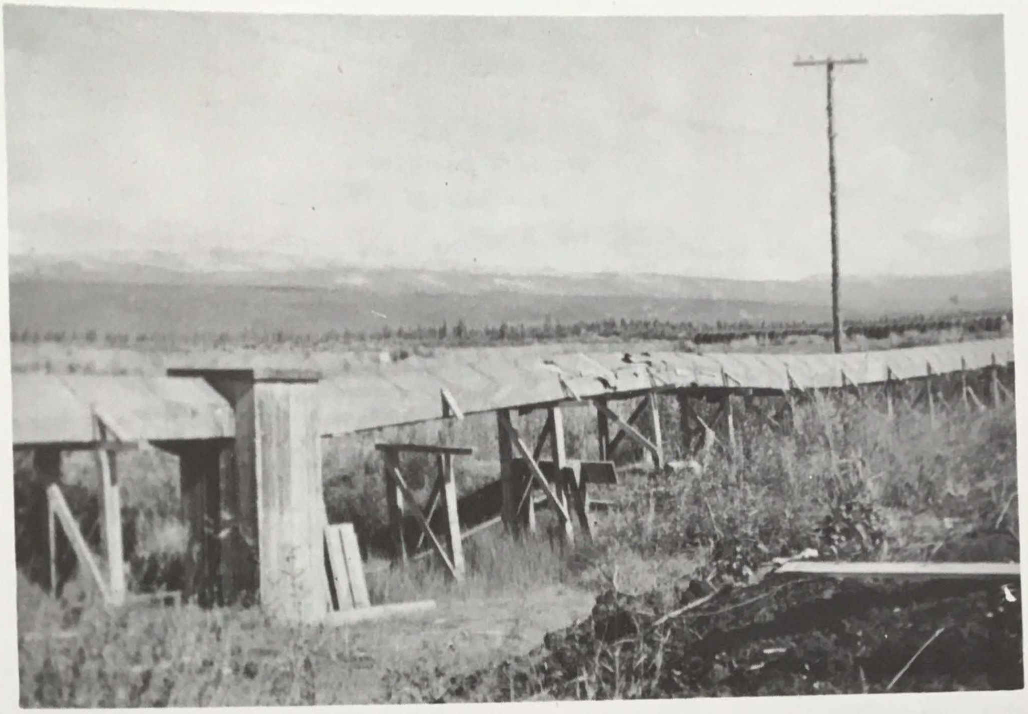


Figure 37

The photo shows a cumulative heave of 20" in small trestle supporting a box protecting service lines. One trestle in the foreground has apparently been anchored in permafrost and has not moved.

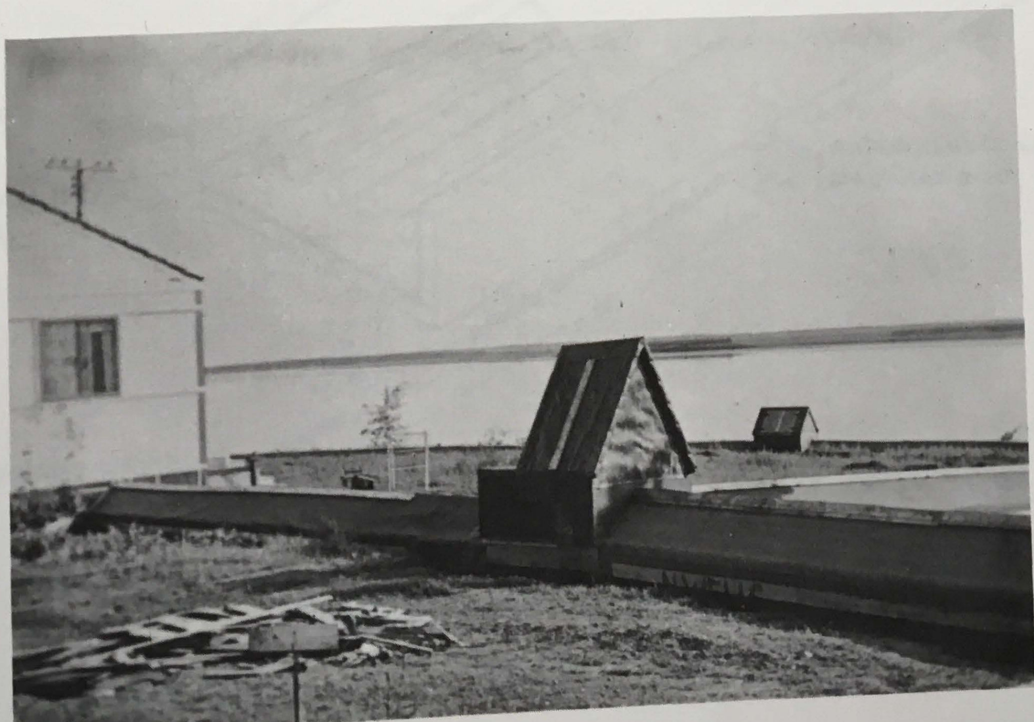
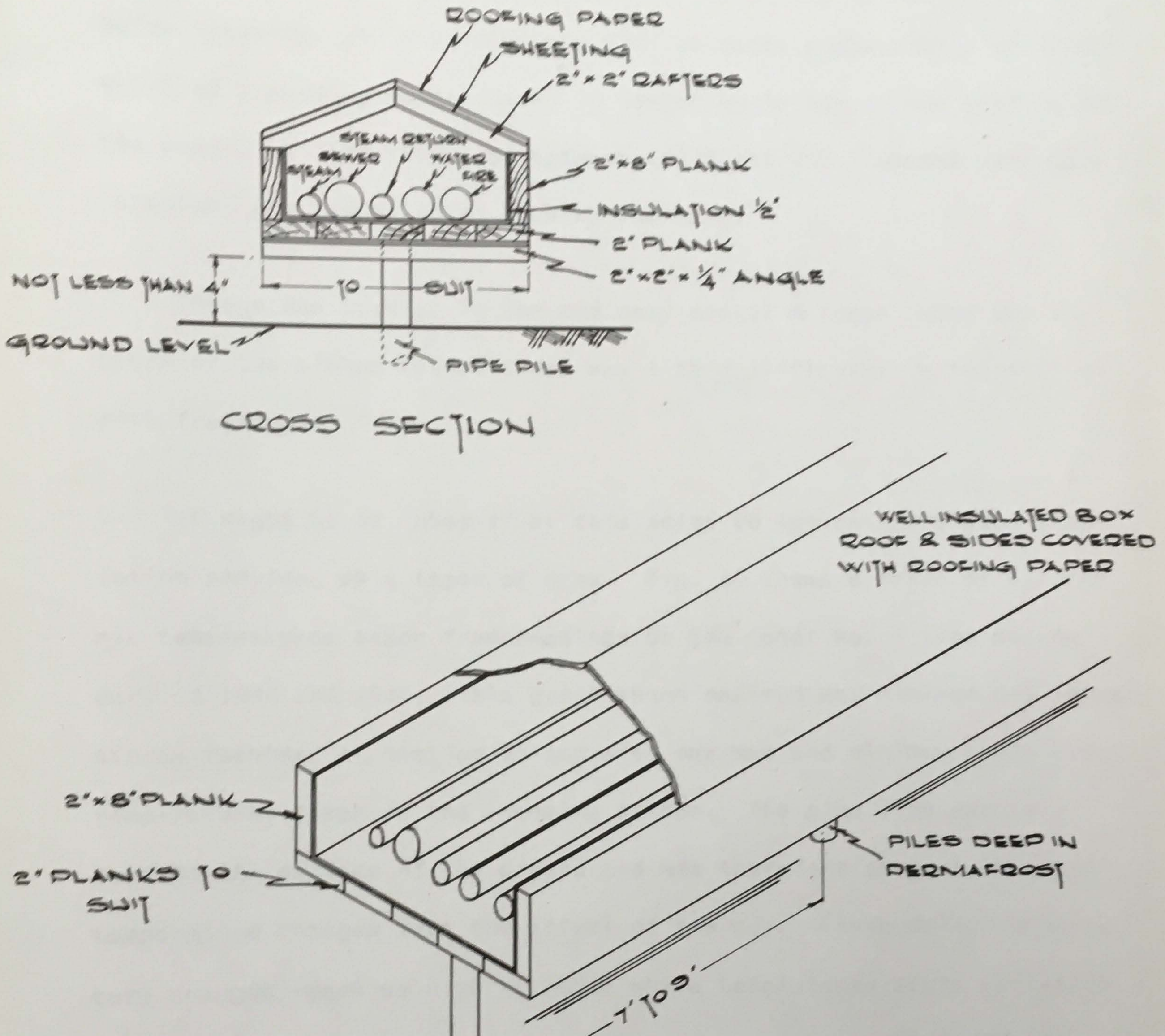


Figure 38

The above photo illustrates how steam and water lines are carried from building to building. The small roofed box houses a fire hydrant.



METHOD OF PROTECTING SERVICE LINES FROM FROST ACTION

FIG. 39

Sewage treatment becomes rather difficult in areas where the average temperature is so low and where the ground temperatures are below freezing. This problem was handled quite successfully at Norman Wells by providing septic tanks in heated buildings at the outflow of the sewer. A temperature of between 60° F and 70° F seemed very satisfactory for the building housing the tank.

Sewage was treated in the ordinary manner in these tanks and because of the siphon action there was little difficulty in the outflow with freezing.

It might be of interest at this point to indicate the good insulation provided by a layer of snow. Fig. 40 shows a graph of oil and air temperatures taken from readings on the Canol No. I line during part of 1944 and 1945. This graph shows maximum and minimum oil temperatures recorded at Station #6 and also maximum and minimum daily air temperatures taken on the incoming stream. The pipe line was laid bare on the surface of the ground and was therefore subject to sharp temperature changes from the effect of the sun. These daily temperature changes reach as high as 66° F while total temperature variation of only 2° or 3° F occurs when the line is covered. These effects are very important in the consideration of any pipeline in the North, and illustrate the need for cover of some sort to prevent rapid temperature changes and resultant high stresses during the summer months.

WATER SUPPLY

The water supply problem is often very difficult in Arctic and Subarctic areas. However, Norman Wells is very well situated in this

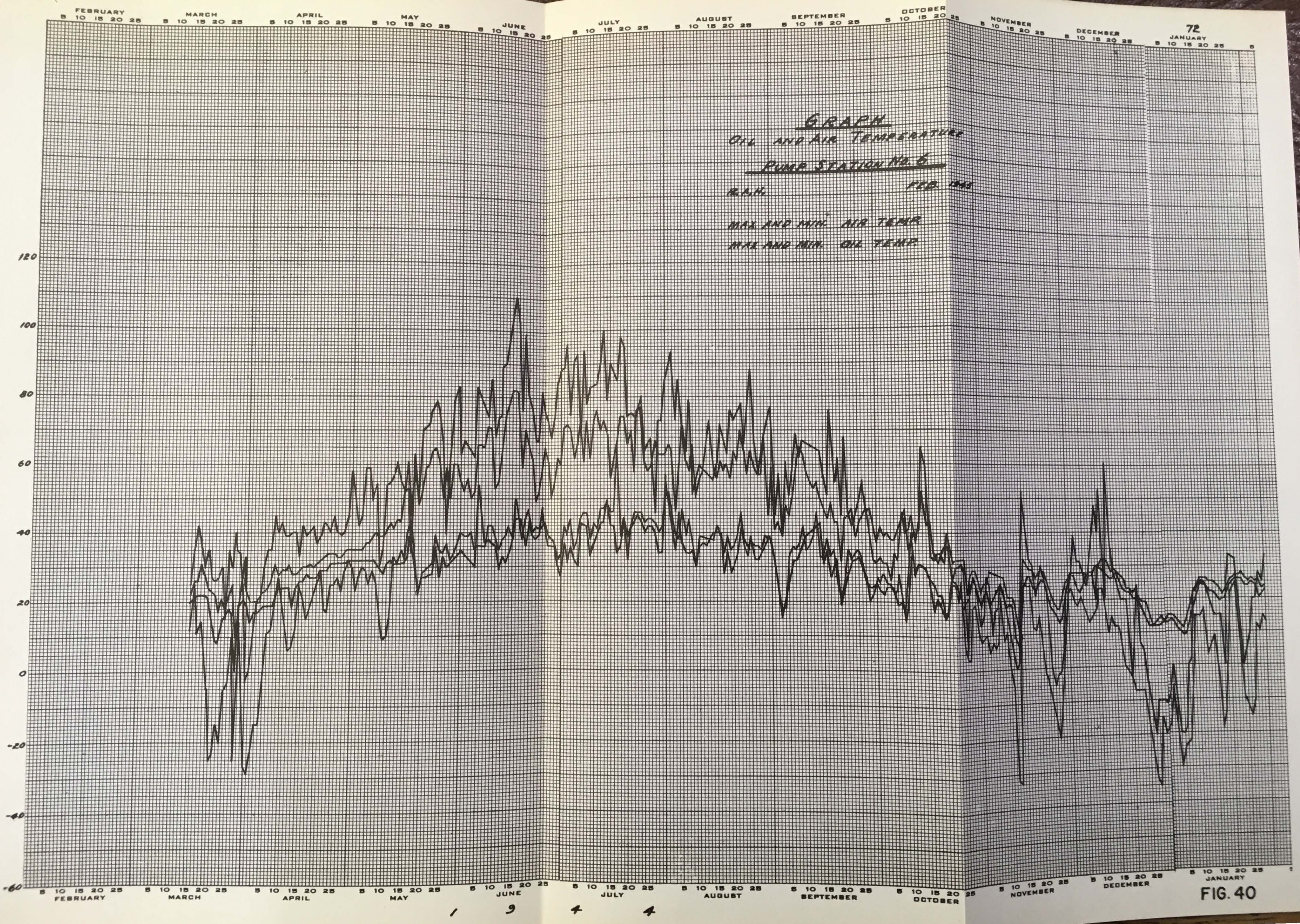

GRAPH
OIL AND AIR TEMPERATURE
PUMP STATION No. 6
R.A.H. FEB. 1945
MAX AND MIN. AIR TEMP.
MAX AND MIN. OIL TEMP.
TEMPERATURE °F
120
100
80
60
40
20
0
-20
-40
-60
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
1 9 4 4

FIG. 40

Figure 41

Even culverts should be set on piles when they may be used to carry any heated lines through the road. The one shown above will be used to carry steam and oil lines as well as drainage.

Figure 42

This photo shows a metal culvert through which steam and return lines were run. The settlement and failure shown here occurred in two years.

regard. It is on the bank of the Mackenzie River and is also very close to Bosworth Creek, which runs year around. Bosworth Creek originates in the Franklin Mountain Range and supplies good clear water to the camp. Water from the Mackenzie was used for some time, the only difficulty being encountered at breakup and freezeup when moving ice forced the removal of the pump suction. Water supply is presently being taken from Bosworth--the flow is not large but it is steady and no ice troubles are encountered in the spring. (i.e. ice does not run). In camps adjacent to Norman Wells some supply has been obtained from drilled wells, but no data is available as to depth or quantity of water. In general the region is fairly well covered with creeks or rivers which run year around and which give an ideal supply. There are also many lakes which do not freeze to the bottom and which could be used as a source of supply if necessary. Water from the active layer has never been used for anything but a temporary supply in emergency and should not be counted on for more than that.

CHAPTER V

ROADS AND AIRPORTS

ROAD CONSTRUCTION

Roadbuilding and airport construction are important in the North especially in those areas where development is going on at a rapid pace. The typical permakeg which causes so many of the difficulties encountered in roadbuilding is very evident at Norman Wells. It was soon determined that stripping off the moss only resulted in forming a deep trench of mud on which it was impossible to found any type of a satisfactory permanent road. At Norman Wells, experience showed that best results were obtained when the moss and brush from both sides of the road were pushed together forming a base for the road. See Fig. 43. This was packed and over it was placed a subgrade from ditches or from borrow pits. By this method it was possible to hold the perma-frost line and even cause it to rise well into the road grade after one or two years. See Figs. 47 and 48. At Norman Wells the subgrade was made from gravel or from a heavy clay available there. Both seemed quite satisfactory, except for some difficulty encountered in frost heaving of certain materials. It is important for good results that the road material should not be material which is susceptible to frost heaving.

FROST HEAVING

There is no need here to go into the theory of frost heaving. It has been shown by Taber and others that frost heaving is due to growth of ice crystals and not to the change in volume effected when

Figure 43

The above photo illustrates how a road base is formed by pushing brush and trees from each side of the road up to form a subgrade. The frost has risen well above that in surrounding areas in the grade shown above.

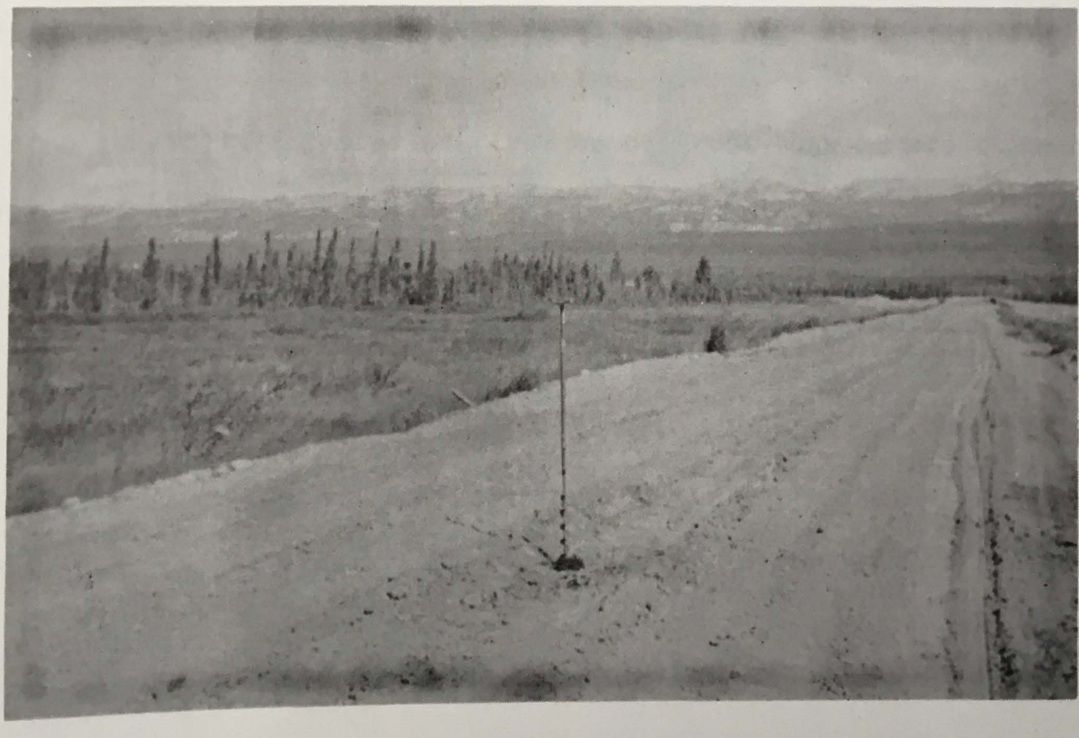


Figure 44

This is the finished roadway which has stood well for four years. The augur is being used to determine the depth of the frostline.

water turns to ice. Pressure is developed in the direction of crystal growth which is usually in the direction of heat transfer. Excessive heaving results when water is pulled up through the soil to build up layers or lenticular masses of segregated ice which grow in thickness because water molecules are pulled into the thin films that separates the growing columnar ice crystals from the underlying soil particles.

Further, it has been shown that this ice segregation is only possible in those soils which are of a grain size suitable to the movement of capillary water. More specifically, A. Casagrande says "under natural freezing conditions and with sufficient water supply, one should expect considerable ice segregation in non uniform soils containing more than 3% of grains smaller than 0.02 mm. and in very uniform soils containing more than 10% smaller than 0.02 mm. No ice segregation has been observed in soils containing less than 1% of grains smaller than 0.02 mm. even if the ground water level was as high as the frost line.

The generally accepted conclusions on frost heaving are summarized by Winn and Rutledge as follows:

1. Destructive frost heaving is almost invariably associated with the formation of segregated ice.

2. The total amount of frost heaving is very closely equal to the sum of the thicknesses of all layers of segregated ice in the frozen soil.

3. The total amount of frost heaving is in direct proportion to the increase in total water content of the frozen soil.

4. The soil must have a water content at least equal to a state of capillary saturation for ice segregation to take place.

5. A supply of water must be available for the growth of ice crystals, either from some portion of the soil itself or from some external source, e.g. ground water table.

6. For normal field conditions of temperature, a certain minimum percentage of grains smaller than 0.02 mm. is necessary for ice segregation in soil.

7. One slow, gradual decrease in temperature, well into the freezing range is necessary and sufficient to cause ice segregation and frost heaving. Subsequent thawing and refreezing may increase the severity of the frost heaving, but will not change the basic action.

8. A cumulative curve of degree-hours of freezing plotted against time is a qualitative measure of the increase of frost heaving with time.

9. The following factors are all necessary for ice segregation and frost heaving. If any one of these factors is not present, frost heaving will not occur:

   (a) Capillary saturation of the soil at the beginning of, or during, the freezing process.

(b) A free supply of water from within or without the soil.

(c) A minimum percentage (3 to 10 per cent) of grains smaller than 0.02 mm.

(d) A gradual decrease in temperature of the air above the soil to below freezing temperatures.

ADMIXTURES

The author has had some opportunity to carry on a few minor experiments on frost heaving. The experiments were primarily done to determine how useful certain admixtures would be in deterring frost action. Figs. 45 and 46 show one of the specimens in which typical frost heaving occurred. The dark lines indicate ice lenses formed under conditions similar to those found in nature. The soil is a silt containing roughly 34% less than 0.02 mm.

Some admixtures are successful in cutting down the total frost heave when they are present in great enough concentration. In the case mentioned above it was found that the admixture (lignosol) a waste product of the pulp and paper industry, when present in percentages of 4% or greater by weight, would practically eliminate frost heaving. From the economic standpoint, this is not feasible for roads or airports but it might be useful in small localized areas such as curling rinks, yards, etc. Experiments on its usefulness to prevent frost heaving of the active layer around piles might also prove very interesting.

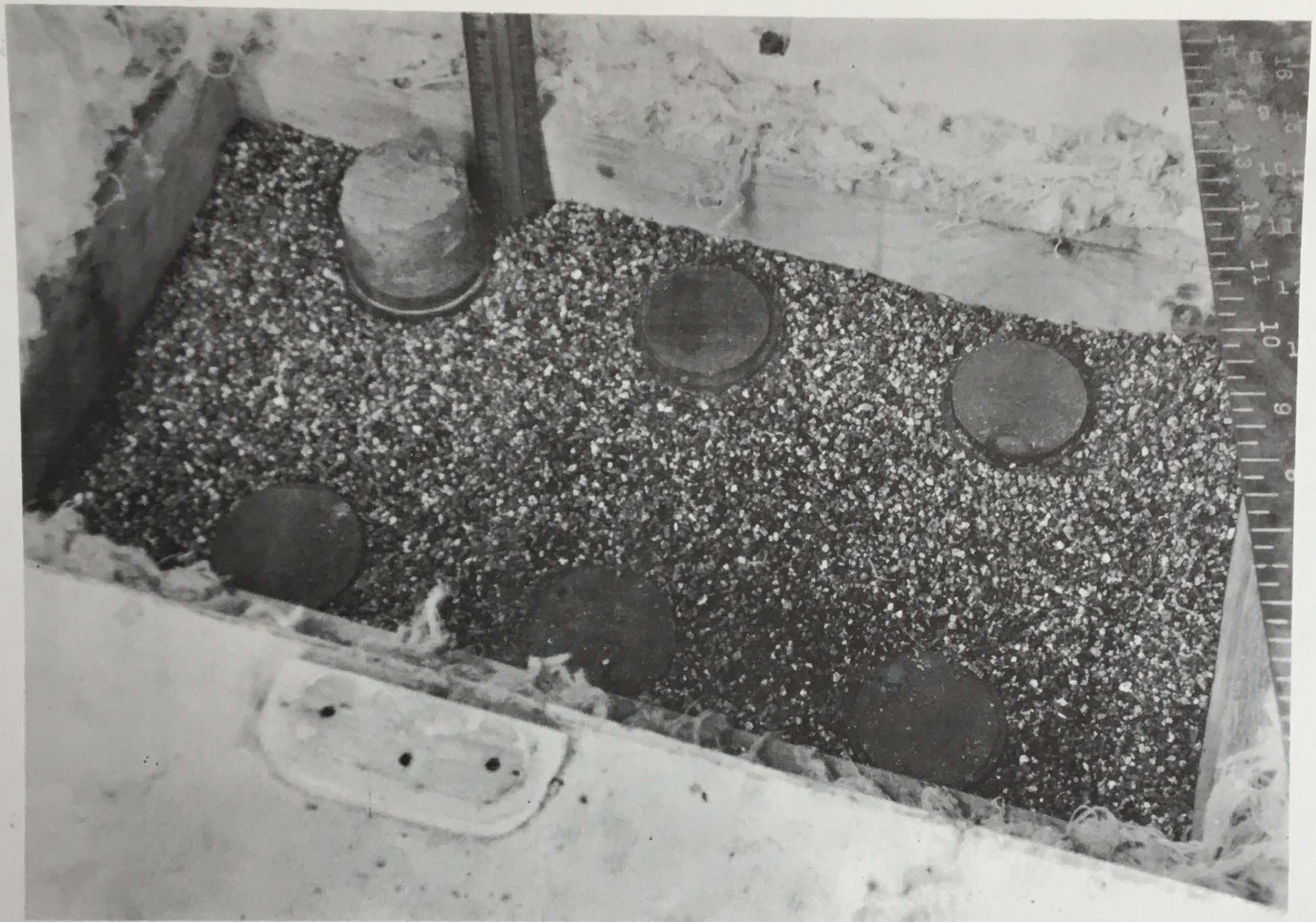


Figure 45

This is a view of six soil samples with varying amounts of admixture. The sample beside the ruler contained no admixture -- ice lenses can be seen in the side of the protruding soil.

Figure 46

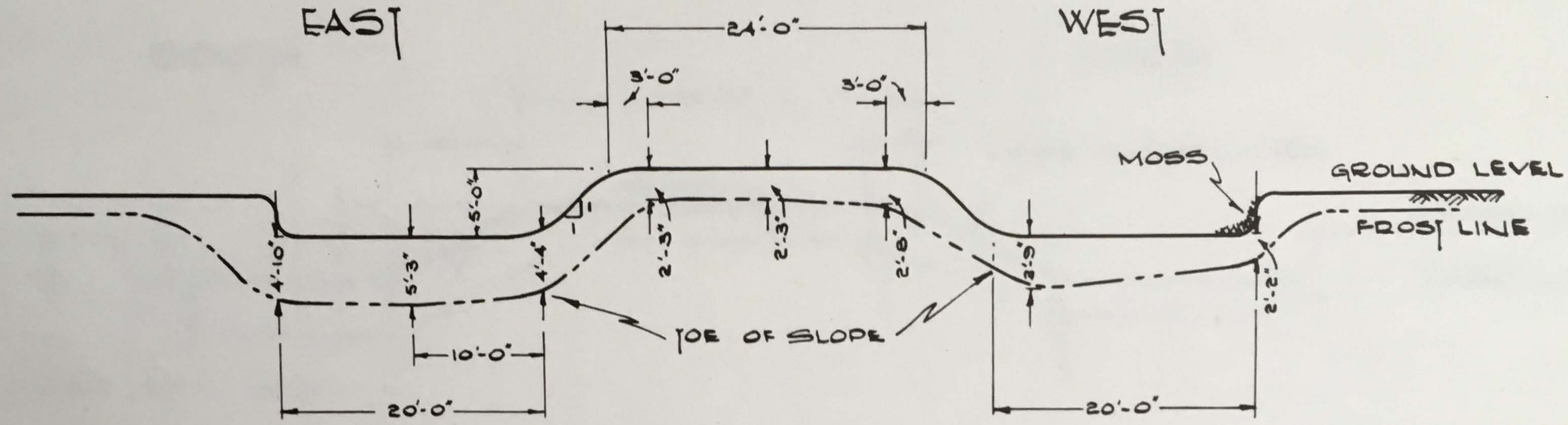
This is a view of the sample of soil without admixture shown in Fig. 45. The thin and regular ice lenses show up well as dark lines around the specimen.

Wherever possible, great care should be taken in selecting subgrade materials for roadbeds or airports. Unfortunately, some of the easily obtained soils of the Norman Wells area are of a type very susceptible to frost action, and therefore the presence of frost boils is often noted on the roads in that area. Drainage was found to greatly improve conditions but did not completely eliminate troubles. Frost heaving troubles are not confined to the North, in fact they are very evident throughout most of Canada. However, the soil type and the fact that presence of permafrost leads to a very high moisture content greatly increases troubles of this nature at Norman Wells. The practice of stopping all heavy traffic, and keeping general traffic to a minimum during the breakup season will prevent much damage to the roads when they are soft due to the excess water from ice layers. This is a generally accepted practice on all roads in the northern parts of Canada.

FROST LINES ON ROADS

Frost line records were taken over several road cross sections and typical examples are presented in Figs. 47 and 48. The measurements of frost depth were made simply by testing with an augur at various locations over the area required. See Fig. 44.

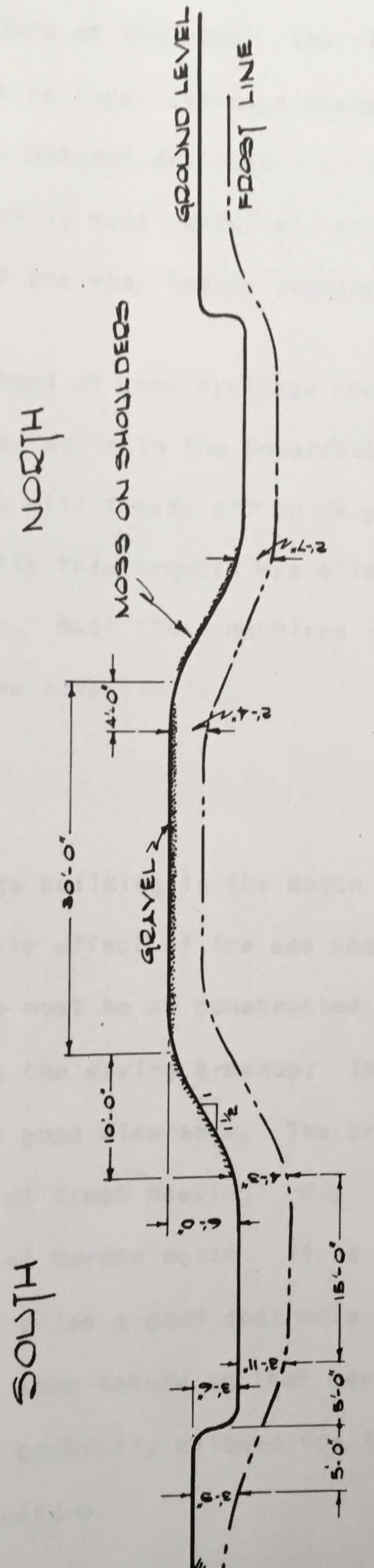
It will be noted that the frostline has risen well into the road grade. This provides good foundation and better drainage for the road surface. Moss and vegetable matter on the shoulders as recommended by Muller have prevented any undue thawing and resulting undercutting of



FROST LINE ON ROAD RUNNING NORTH & SOUTH
IN A MUSKEG AREA

FROST LINE IN GENERAL AREA ABOUT 16" BELOW SURFACE

FIG. 47



FROST LINE ON ROAD RUNNING EAST & WEST

FROST LINE IN GENERAL AREA ABOUT 22" BELOW SURFACE

FIG. 48

the shoulders of the road. The rise in permafrost table may seriously effect active layer drainage where the road has been constructed across the natural drainage. In this case ditching is very important and is usually most useful at some distance from the road to prevent erosion of the road bed by running water.

The need of good drainage cannot be overemphasized for permanent roads or airports in the Subarctic areas. Culverts through a road in permafrost will freeze off quickly during the spring and fall. At Norman Wells this trouble was eliminated by the use of portable steam generators. With these machines it is possible to open up culverts quickly and effectively.

BRIDGES

Bridge building in the North calls for careful consideration of the possible effect of ice and snow. Bridges on the larger streams and rivers must be so constructed that they will allow for passage of ice during the spring breakup. This in general means longer clear spans with good clearance. The bridge abuttments also may give trouble by reason of frost heaving. Fig. 49 shows a small bridge of pile construction at Norman Wells. It is obvious here that frost has heaved one row of piles a good deal more than any others. This frost heaving is the same nature as that described in other places in this paper, and if not carefully allowed for in design, may cause complete failure of the structure.

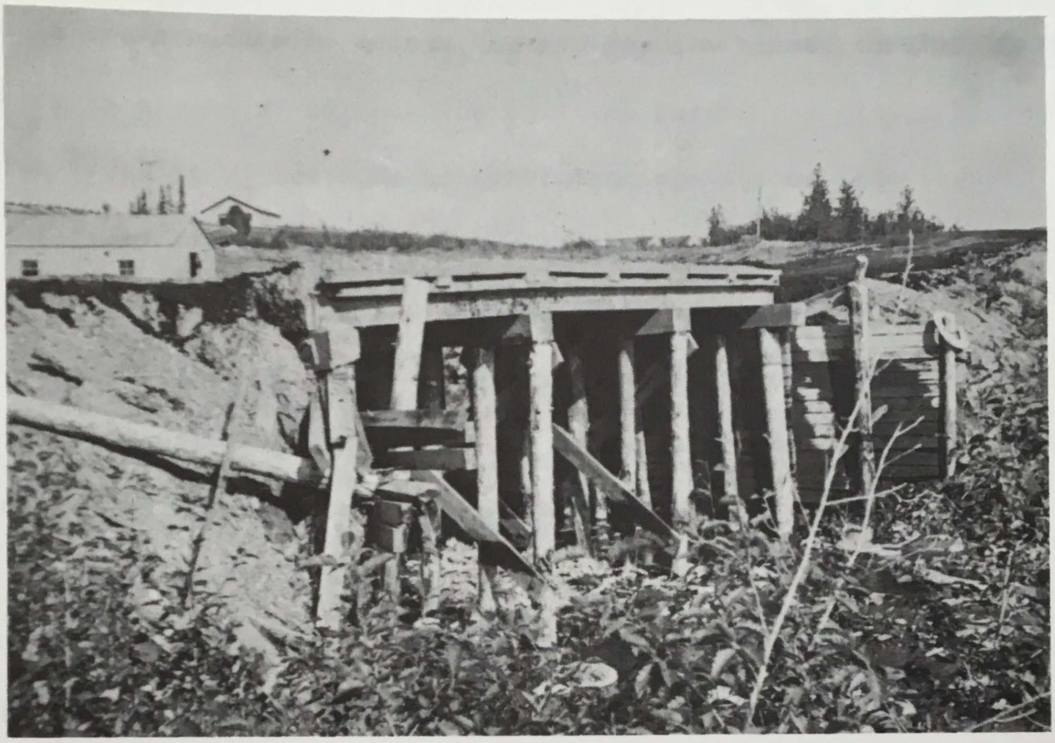


Figure 49

The piles in the two middle bents of this small bridge have heaved because of frost action.

ICINGS

Another serious difficulty in the maintenance of roads in the North is the presence of icings, or as they are termed locally "glaciers". An icing is a mass of surface ice built up during the winter by successive freezing of seepages of water from springs or from beneath lake or river ice. Since the water may break forth in large quantities and under considerable pressure, trouble may be caused in a relatively short time. Fig. 50 shows a typical icing along a creek bed--here a continual breaking out of the creek water has built up a layer of ice ten to fifteen feet thick. Pockets of water in the ice make the road treacherous and nearly impassable. This trouble could only be eliminated by a continual maintenance during which this road is built up by pumping water to form a high and thick road of ice which would not be reached by the normal outbreaks of water from the creek bed. Probably in most cases of this type the cheapest method would be to reroute the road to bypass such areas. Fig. 52 shows icing formed by springs or outbreaks of water trapped between surface frost and permafrost. Control has been effected by supplying sufficient heat to the water so that it may be led away from the road before it freezes. This method is of course very expensive and would not likely be economically feasible except at an oil field where there was an ample supply of cheap fuel. Fig. 56 shows oil stoves developed for combatting freezing. Portable steam generators have been used to control small icings of this type. Tractor drawn rooters or plows have been used also to break up and remove ice from the road surface. This me-

Figure 50

Icing conditions in a canyon. Water breaks out and covers the road to a depth of two or three feet. Depth of ice indicated by the tops of telephone poles which protrude only about 6' above the ice.

Figure 51

Areas such as this are very difficult to maintain clear of snow. The wind blows almost constantly on these higher reaches.

Figure 52

A tractor drawn rooter has been used to break up the ice from the small sidehill icing. This icing is very small but nevertheless blocks the road entirely as the sloping ice forces all traffic off the road.

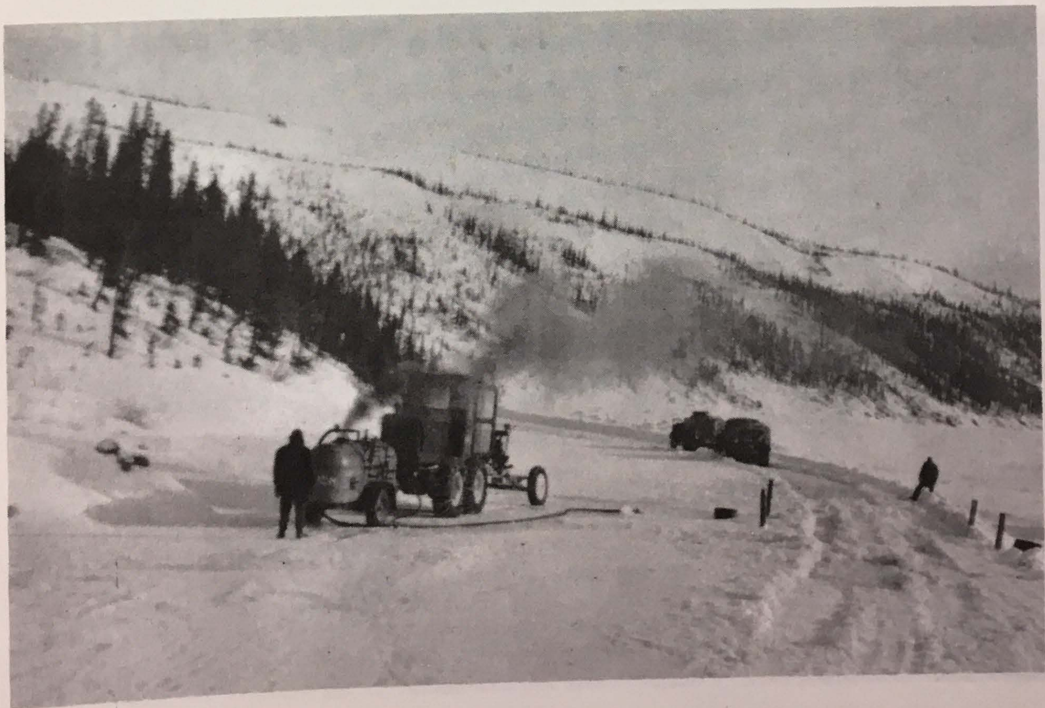


Figure 53

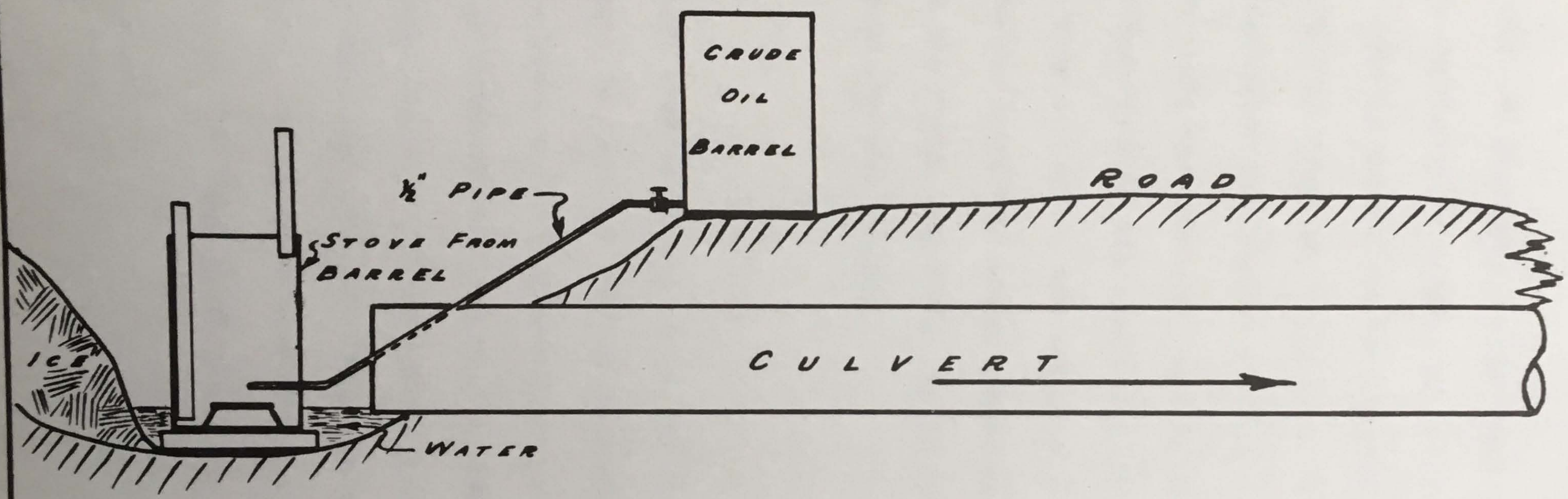
A portable steam generator is being used to thaw a culvert in order to carry away excess water from the upper side of the road.

Figure 54

This is a photo of an icing which has progressed down the small valley. It is being held back from the road by burning oil in the barrels shown along the face of the ice.

Figure 55

A view of the face of an icing which is being held away from the road by burning oil in the barrels shown. This heated the water sufficiently to pass it through the road culvert and down the valley where the formation of ice will cause no trouble.



HEATER
for
GLACIER CONTROL

R.A.H.

FEB. 1945

FIG. 56

thod of control is of course expensive too and has the added difficulty that it requires heavy machinery during the coldest part of the winter when maintenance and personnel problems are most difficult.

The high cost and inconvenience of the above methods of icing control indicate the necessity of getting at the source of the trouble and preventing it. Russian scientists have developed very effective control measures--the best known one being the frost belt. A frost belt consists of a specially constructed ditch the primary object of which is to cause an early and complete freezing of the active layer far enough from the road so that the resulting icing will not damage the road bed. This type of control has not been used around Norman Wells, but the author believes that where ground water or spring icings cause trouble the frost belt would be the cheapest and most effective way of combatting the trouble.

SNOW

In Subarctic areas such as Norman Wells, drifting snow is a constant source of trouble in road and airport maintenance during the winter months. It is especially troublesome on open roads across lakes and rivers or on roads which climb to the higher barren reaches of hills and mountains. The only methods used to date to keep roads open in the area have been the provision of enough machinery to plow the snow from the roads. This however, is very expensive over a period of time, and would be difficult to maintain over any long stretch

of road. Rotary snow plows which spread the snow and eliminate the high banks are most satisfactory, but are also more expensive to operate. Most of the snow clearing done locally at Norman Wells was done by bulldozers or motor graders. Operation was fairly satisfactory for yards and short stretches of roads.

In many areas the building up of roadbeds so that they are well above surrounding land will keep the road free of drifting snow, and greatly lessen the work of snow clearing. A judicious use of snow fencing also proves useful in some areas. The small spruce of the area when cut and placed in a row make an ideal snow fence.

AIRPORTS

The advent of the second Great War brought about the building of many airports in the northern parts of Canada. The airport at Norman Wells is built on a glacial esker running parallel to the Mackenzie River. By reason of its being well above the surrounding ground, the problem of snow removal was greatly lessened. Moreover the general drainage is very good and no problems were encountered with permafrost or any factors peculiar to the North. The airport at Canol was built on a low flat area, underlain by permafrost just across the Mackenzie River from Norman Wells. It was constructed simply by putting a heavy gravel fill twenty-four inches thick over the whole area. Since this airport was only used for a short period, no results are obtainable on the advisability of using this type of construction.

No airports in the district have been surfaced so it is difficult to say how pavements would last on airports of this type.

In general, it can be seen that permafrost is especially important in considering any type of earth work, whether for roads, yards or airports. However, it does not present any problems which cannot be overcome by a careful planning after consideration of all the properties and conditions of the permafrost in the area

CHAPTER VI

COMMUNICATION

Nearly all modern methods of communication have been used at Norman Wells, including the telephone and radios of several types.

During the Canol Project there was a two wire magneto type telephone system connecting Norman Wells and Whitehorse, Y.T., roughly five hundred and eighty miles south-west. The system operated fairly well although it should be noted that heavy frost accumulations on the lines cut down the transmission efficiency and required rather constant maintenance to insure good operation. This effect was not noticeable on the short local lines at Norman Wells. Difficulties were found however in maintaining pole lines through swampy, permafrost areas. In such areas frost heaving pulled the poles from the ground in very short time. Fig. 58 shows a pole line which had been heaved to the surface in two seasons. Originally the poles had been set to a depth of four and a half to five feet. Fig. 57 shows a power and telephone line through similar ground which fell over after four seasons. One solution to this problem would be the driving of piles and anchoring of poles to the piles. The use of cross braced poles such as are used in swamps is also a satisfactory method of preventing poles from upsetting.

Radio links to small settlements close to Norman Wells have been used. However they were not entirely satisfactory. Certain areas in the vicinity are subject to radio blackouts which only powerful trans-

Figure 57

A power line at point of failure due to heaving of poles. Brush subgrade can be seen to left of line.

Figure 58

The pole line here was heaved out of the ground by frost action in two seasons. The box for service lines has been badly heaved also.

mitters on low frequencies were able to penetrate.

TRANSPORTATION

As would be expected, conditions in the North are very severe on motor vehicles. The cold and lack of good roads tend to shorten the life of any vehicle and narrows the choosing of suitable machines for the North. Ordinary cars and trucks can be used where roads are maintained, provided adequate heated storage and servicing is provided. The light "snowmobile" type vehicle with skiis on the front and a track type drive is suitable and useful in river and lake travel, and will negotiate severe snow conditions with ease.

Summer travel overland is nearly impossible--the only vehicles which have been successful so far are track type tractors or trucks with track type drive. These too find movement late in the summer almost impossible by reason of the deep wet swamps encountered.

The native mode of travel--by canoe in summer and by dog team in the winter is still often the fastest and most adaptable means of getting around the country.

Planes equipped with skiis in winter and floats in summer are very useful in servicing scattered areas, but have the disadvantage that they cannot be used during breakup or freezeup. These periods often amount to two or three months each season.

All heavy supplies for Norman Wells are taken in during the summer

by shallow draft tugs and barges which ply the Mackenzie River. The trip is long and slow and rates are high so that operations are often modified greatly by the lack of good year round connections with the agricultural and manufacturing areas of the rest of Canada.

It seems obvious since so much wealth in furs, oil, gold, radium, and other minerals have been found in the North by the relatively small amount of exploration carried out so far, that this area is destined to become one of the richest and most important in all of Canada. The climate is not the best but with proper clothing and good housing, it offers but little opposition to development there. The frozen soils add somewhat to the hazards and expense of any engineering problem, but with proper engineering methods and careful study of the area involved, development will not be stopped. However, as in other remote areas of Canada, the North will only develop to its full extent when cheap reliable, year round transportation is available to carry products to market and to keep people who live in the North in closer touch with the rest of the world.

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